



Search for Higgs and Z Boson Decays to ϕ γ with the ATLAS Detector

Aaboud, M.; Aad, G.; Abbott, B.; Abdallah, J.; Abdinov, O.; Abeloos, B.; Aben, R.; AbouZeid, O.S.; Abraham, N.L.; Abramowicz, H.; Dam, Mogens; Hansen, Jørn Dines; Hansen, Jørgen Beck; Xella, Stefania; Hansen, Peter Henrik; Petersen, Troels Christian; Thomsen, Lotte Ansgaard; Pingel, Almut Maria; Løvschall-Jensen, Ask Emil; Alonso Diaz, Alejandro; Monk, James William; Pedersen, Lars Egholm; Wiglesworth, Graig; Galster, Gorm Aske Gram Krohn

Published in:
Physical Review Letters

DOI:
[10.1103/PhysRevLett.117.111802](https://doi.org/10.1103/PhysRevLett.117.111802)

Publication date:
2016

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Aaboud, M., Aad, G., Abbott, B., Abdallah, J., Abdinov, O., Abeloos, B., Aben, R., AbouZeid, O. S., Abraham, N.L., Abramowicz, H., Dam, M., Hansen, J. D., Hansen, J. B., Xella, S., Hansen, P. H., Petersen, T. C., Thomsen, L. A., Pingel, A. M., Løvschall-Jensen, A. E., ... Galster, G. A. G. K. (2016). Search for Higgs and Z Boson Decays to ϕ γ with the ATLAS Detector. *Physical Review Letters*, 117(11), [11802].
<https://doi.org/10.1103/PhysRevLett.117.111802>

Search for Higgs and Z Boson Decays to $\phi\gamma$ with the ATLAS Detector

M. Aaboud *et al.**

(ATLAS Collaboration)

(Received 14 July 2016; published 9 September 2016)

A search for the decays of the Higgs and Z bosons to a ϕ meson and a photon is performed with a pp collision data sample corresponding to an integrated luminosity of 2.7 fb^{-1} collected at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector at the LHC. No significant excess of events is observed above the background, and 95% confidence level upper limits on the branching fractions of the Higgs and Z boson decays to $\phi\gamma$ of 1.4×10^{-3} and 8.3×10^{-6} , respectively, are obtained.

DOI: 10.1103/PhysRevLett.117.111802

Rare decays of the 125 GeV Higgs boson [1,2] H to a light meson and a photon γ have been suggested to present one viable probe of the Yukawa coupling of the Higgs boson to light (u , d , s) quarks [3–5]. While the Standard Model (SM) predicts these couplings to be small, substantial modifications are predicted in several scenarios beyond the SM, which include the minimal flavor violation framework [6], the Froggatt-Nielsen mechanism [7], the Higgs-dependent Yukawa couplings model [8], the Randall-Sundrum family of models [9], and the possibility of the Higgs boson being a composite pseudo-Goldstone boson [10]. The light-quark Yukawa couplings are almost entirely unconstrained by existing data and the large multijet background at the Large Hadron Collider (LHC) severely inhibits the study of such couplings with inclusive $H \rightarrow q\bar{q}$ decays. The decay of the Higgs boson to a ϕ meson and a photon would give access to the strange-quark Yukawa coupling and to potential deviations from the SM prediction. The expected SM branching fraction is $\mathcal{B}(H \rightarrow \phi\gamma) = (2.3 \pm 0.1) \times 10^{-6}$ [4], and no direct experimental information about this decay mode currently exists. The analogous rare decays of the Higgs boson to a heavy quarkonium state and a photon offer sensitivity to the charm- and bottom-quark Yukawa couplings [11–13]. The Higgs boson decays to $J/\psi\gamma$ and $\Upsilon\gamma$ have already been searched for by the ATLAS Collaboration [14]. The former decay mode has also been searched for by the CMS Collaboration [15].

The corresponding decay of the Z boson has also been considered from a theoretical perspective [16,17], as it offers a precision test of the SM and the predictions of the factorization approach in quantum chromodynamics [17]. Owing to the large Z boson production cross section at the LHC, rare Z boson decays can be probed at branching

fractions much smaller than for Higgs boson decays to the same final state. The most precise prediction for the SM branching fraction is $\mathcal{B}(Z \rightarrow \phi\gamma) = (1.17 \pm 0.08) \times 10^{-8}$ [16]. The decay $Z \rightarrow \phi\gamma$ has not yet been observed and is not well constrained by existing measurements of Z boson decays.

This Letter describes a search for Higgs and Z boson decays to the exclusive final state $\phi\gamma$. The decay $\phi \rightarrow K^+K^-$ is used to reconstruct the ϕ meson. The search is performed with a sample of pp collision data corresponding to an integrated luminosity of 2.7 fb^{-1} recorded at a center-of-mass energy $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector, described in detail in Ref. [18].

Higgs boson production is modeled using the POWHEG-BOX v2 Monte Carlo (MC) event generator [19–23] for the gluon fusion (ggH) and vector-boson fusion (VBF) processes calculated up to next-to-leading order in α_s with CT10 parton distribution functions [24]. Additional contributions from the associated production of a Higgs boson and a W or Z boson (denoted WH and ZH , respectively) are modeled by the PYTHIA 8.186 MC event generator [25,26] with NNPDF 2.3 parton distribution functions [27]. The production rates and dynamics for a SM Higgs boson with $m_H = 125 \text{ GeV}$, obtained from Ref. [28], are assumed throughout this analysis. The ggH signal model is appropriately scaled to account for the production of a Higgs boson in association with a $t\bar{t}$ or $b\bar{b}$ pair. The POWHEG-BOX v2 MC event generator, with the CTEQ6L1 parton distribution functions [29], is used to model Z boson production. The total cross section is obtained from the measurement in Ref. [30], with an uncertainty of 5.5%.

The Higgs and Z boson decays are simulated as a cascade of two-body decays. Effects of the helicity of the ϕ mesons on the K^\pm kinematics are found to modify the acceptance by at most $\pm 1\%$ and this is corrected for in the Higgs boson case and treated as a systematic uncertainty in the Z boson case, due to the unknown Z boson polarization.

PYTHIA 8.186 [25,26] with the AZNLO set of hadronization and underlying-event parameters [31] is used to simulate showering and hadronization. The simulated

*Full author list given at the end of the article.

Published by the American Physical Society under the terms of the Creative Commons Attribution 3.0 License. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

events are passed through the detailed GEANT4 simulation of the ATLAS detector [32,33] and processed with the same software used to reconstruct data.

The data sample used in this analysis was collected with a dedicated trigger, commissioned in September 2015, requiring an isolated photon with a transverse momentum p_T greater than 35 GeV and an isolated pair of tracks with an invariant mass loosely consistent with the ϕ meson mass of 1019.5 MeV [34], one of which must have a transverse momentum greater than 15 GeV. The trigger efficiency for both the Higgs and Z boson signals is around 80% with respect to the offline selection. Events are retained for analysis if collected under stable LHC beam conditions and the detector was operating normally.

For this analysis, in the absence of particle identification capabilities in the relevant momentum range, every reconstructed charged particle satisfying the following requirements is assumed to be a K^\pm meson. Events are selected if there are at least two tracks with $p_T > 400$ MeV originating from the primary vertex, which is defined as the vertex with the largest $\sum p_T^2$ in the event. The charged kaons are reconstructed from inner-detector tracks that satisfy quality requirements, including a requirement on the number of hits in the silicon detectors [35]. The K^\pm candidates are required to have pseudorapidity [36] $|\eta| < 2.5$ and $p_T > 15$ GeV. The $\phi \rightarrow K^+K^-$ decays are reconstructed from pairs of oppositely charged inner detector tracks. The higher- p_T track in a pair, denoted the leading track, is required to have $p_T > 20$ GeV. The experimental resolution in $m_{K^+K^-}$ is around 4 MeV, comparable to the natural width of the ϕ meson, $\Gamma_\phi = 4.266 \pm 0.031$ MeV [34]. Track pairs with a mass $m_{K^+K^-}$ within ± 20 MeV of the ϕ meson mass [34] are selected as $\phi \rightarrow K^+K^-$ candidates. Selected $\phi \rightarrow K^+K^-$ candidates are required to satisfy an isolation requirement: the sum of the p_T of the reconstructed inner detector tracks from the main vertex within $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.2$ of the leading track (excluding both tracks constituting the $\phi \rightarrow K^+K^-$ candidate) is required to be less than 10% of the p_T of the ϕ candidate, $p_T^{K^+K^-}$.

Photons are reconstructed from clusters of energy in the electromagnetic calorimeter. Clusters without matching tracks are classified as unconverted photon candidates while clusters matched to tracks consistent with the hypothesis of a photon conversion into an e^+e^- pair are classified as converted photon candidates [37]. Reconstructed photon candidates are required to have transverse momentum $p_T^\gamma > 35$ GeV, pseudorapidity $|\eta^\gamma| < 2.37$, excluding the barrel or endcap calorimeter transition region $1.37 < |\eta^\gamma| < 1.52$, and to satisfy the “tight” photon identification criteria [38]. An isolation requirement is imposed to further suppress the contamination from jets. The sum of the transverse momenta of all tracks within $\Delta R = 0.2$ of the photon direction, excluding those associated with the reconstructed photon, is required to be less than 5% of p_T^γ . The effects of

multiple pp interactions per bunch crossing (pile-up) in this calculation are reduced by removing tracks that do not originate from the primary vertex. Additionally, the sum of the transverse momenta of all energy deposits in the calorimeters within $\Delta R = 0.4$ of the photon direction, excluding those associated with the reconstructed photon, is required to be less than $(2.45 \text{ GeV} + 0.022 \times p_T^\gamma)$. The calorimeter isolation measurements are also corrected for the effects of pile-up.

Combinations of a $\phi \rightarrow K^+K^-$ candidate and a photon, satisfying $\Delta\phi(K^+K^-, \gamma) > 0.5$, are retained for further analysis. When multiple combinations are possible, the combination of the highest- p_T photon and the $\phi \rightarrow K^+K^-$ candidate with a mass closest to the ϕ meson mass is retained. The transverse momentum of $\phi \rightarrow K^+K^-$ candidates is required to be greater than a threshold that varies as a function of the invariant mass of the three-body system, $m_{K^+K^-\gamma}$. Thresholds of 40 GeV and 45 GeV are imposed for the regions $m_{K^+K^-\gamma} < 91$ GeV and $m_{K^+K^-\gamma} \geq 125$ GeV, respectively. The threshold is varied from 40 GeV to 45 GeV as a linear function of $m_{K^+K^-\gamma}$ in the region $91 \leq m_{K^+K^-\gamma} < 125$ GeV. This approach ensures optimal sensitivity for both the Higgs and Z boson searches. The total signal efficiency (kinematic acceptance, and trigger and reconstruction efficiencies) is 18% and 8% for the Higgs and Z boson decays, respectively. The difference in efficiencies primarily arises due to the softer p_T^γ and $p_T^{K^+K^-}$ distributions in the case of $Z \rightarrow \phi\gamma$ production. The $m_{K^+K^-}$ resolution is around 1.8% for both the Higgs and Z boson decays. The $m_{K^+K^-}$ distribution for selected $\phi\gamma$ candidates, with no $m_{K^+K^-}$ requirement applied, is shown in Fig. 1 and exhibits a clear peak at the ϕ meson mass.

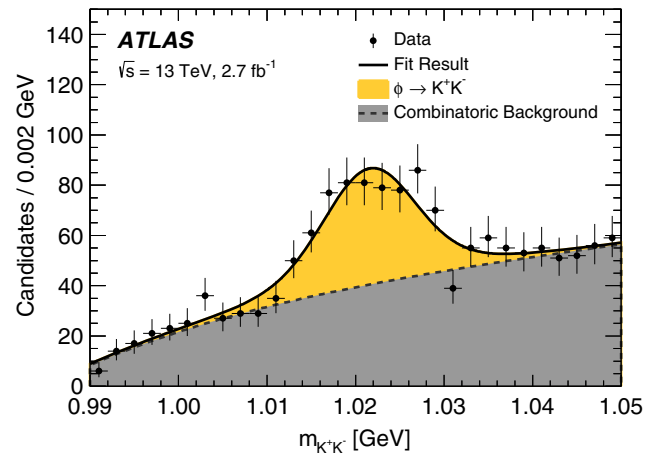


FIG. 1. The $m_{K^+K^-}$ distribution of selected $\phi\gamma$ combinations with the complete event selection applied (see text), apart from the requirement on $m_{K^+K^-}$. The data are fitted with the convolution of a Breit-Wigner distribution, using the ϕ width [34], and a Gaussian distribution to represent the experimental resolution, while the background is modeled with an analytical function, commonly used to describe a kinematic threshold [39].

The main source of background to the search comes from events involving inclusive multijet or photon + jet processes where a $\phi \rightarrow K^+K^-$ candidate is reconstructed from tracks associated with a jet. The normalization of this inclusive background is extracted directly from a fit to data. The selection criteria discussed earlier shape the $m_{K^+K^-}$ distribution for background such that it exhibits a threshold structure near 100 GeV, and falls then smoothly towards higher mass values. Given the nontrivial shape of this background, these processes are modeled with a nonparametric data-driven approach using templates to describe the kinematic distributions. A similar procedure was used in the search for Higgs and Z boson decays to $J/\psi\gamma$ and $\Upsilon(nS)\gamma$ described in Ref. [14]. The approach exploits a sample of around 4000 K^+K^- candidate events passing all of the kinematic selection requirements described previously, except that the photon and $\phi \rightarrow K^+K^-$ candidates are not required to satisfy the nominal isolation requirements. The events satisfying this selection are collected in a generation region (GR). The contamination of this sample from signal events is expected to be negligible and is verified not to affect the shape of the background model. Probability density functions (pdfs) that model the $p_T^{K^+K^-}$, p_T^γ , $\Delta\eta(K^+K^-, \gamma)$, and $\Delta\phi(K^+K^-, \gamma)$ distributions of this sample are constructed using a Gaussian kernel density estimation [40]. Correlations between these variables and p_T^γ in the event were studied and accounted for in the background model by deriving separate pdfs in 13 exclusive regions of p_T^γ . In the case of the $\phi \rightarrow K^+K^-$ and photon isolation variables, correlations are accounted for by using two-dimensional histograms derived in the same 13 exclusive regions of p_T^γ . Values of $m_{K^+K^-}$ are sampled from the corresponding distribution in the GR. The pdfs of these kinematic and isolation variables are sampled to generate an ensemble of pseudocandidates, each with a complete K^+K^- four-vector and an associated pair of $\phi \rightarrow K^+K^-$ and photon isolation values. The nominal selection requirements are imposed on the ensemble and the surviving pseudocandidates are used to construct templates for the $m_{K^+K^-}$ distribution.

To validate this background model with data, the $m_{K^+K^-}$ distributions in several validation regions, defined by kinematic and isolation requirements looser than the nominal signal requirements, are used to compare the prediction of the background model with the data. The $m_{K^+K^-}$ distribution in one of these validation regions, defined by the GR selection with the addition of the nominal photon isolation requirement, is shown in Fig. 2. The background model is found to describe the data well, and within the observed statistical uncertainties. A consistency test of the background modeling procedure has been performed with a sample of simulated photon + jet events in place of the data; similarly good agreement is observed. The robustness of the background model is further validated by splitting the data into high- and low- $p_T^{K^+K^-}$ subsets, that exhibit different

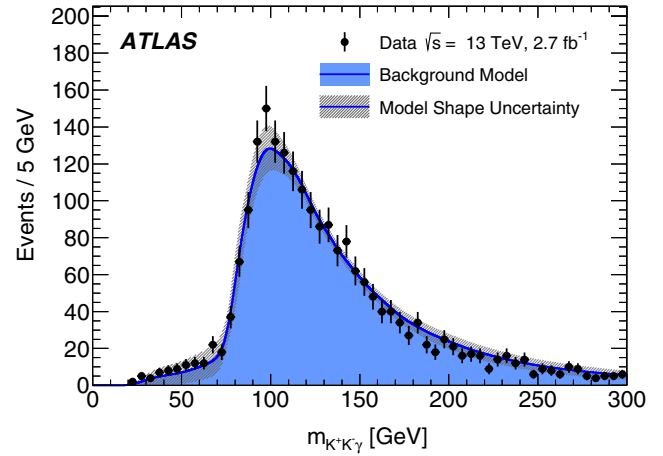


FIG. 2. The distribution of $m_{K^+K^-}$ in data compared to the prediction of the background model for a validation control sample defined by the GR selection with the addition of the nominal photon isolation requirement. The background model is normalized to the observed number of events within the region shown. The uncertainty band corresponds to the uncertainty envelope derived from variations in the background modeling procedure.

threshold structures, and confirming that the background model describes the shapes of both $m_{K^+K^-}$ distributions. Further exclusive background contributions from $Z \rightarrow \ell\ell\gamma$ decays have been studied but are found to represent a negligible contribution for the selection requirements and data set used in this analysis.

Trigger and identification efficiencies for photons are determined from samples enriched with $Z \rightarrow e^+e^-$ events in data [37,41]. The systematic uncertainty on the expected signal yield associated with the trigger efficiency is estimated to be 2%. The photon identification efficiency uncertainties, for both the converted and unconverted photons, are estimated to be 2.4% and 2.6% for the Higgs and Z boson signals, respectively. An uncertainty of 6% is assigned to the track reconstruction efficiency and includes effects associated with the material budget of the inner detector and the behavior of the track reconstruction algorithm if a nearby track is present. The integrated luminosity of the data sample has an uncertainty of 5% derived using the method described in Ref. [42]. The

TABLE I. The number of observed events and the expected background yield for the two $m_{K^+K^-}$ ranges of interest. The Higgs and Z boson contributions expected for branching fraction values of 10^{-3} and 10^{-6} , respectively, and estimated using Monte Carlo simulations are also shown.

Observed (expected) background				Expected signal	
Mass range [GeV]				Z	H
All	81–101	120–130		$\mathcal{B}[10^{-6}]$	$\mathcal{B}[10^{-3}]$
1065	288 (266 ± 9)	89 (87 ± 3)		6.7 ± 0.7	13.5 ± 1.5

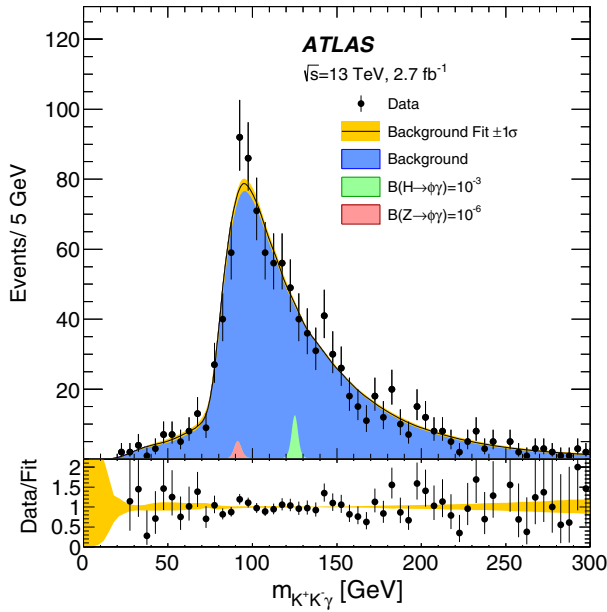


FIG. 3. The $m_{K^+K^-\gamma}$ distributions of the selected $\phi\gamma$ candidates, along with the results of the maximum-likelihood fit with background-only model. The 1σ uncertainty band corresponds to the total uncertainty of the background model. The Higgs and Z boson contributions, expected for branching fraction values of 10^{-3} and 10^{-6} , respectively, are also shown.

photon energy scale uncertainty, determined from $Z \rightarrow e^+e^-$ events and validated using $Z \rightarrow \ell\ell\gamma$ events [43], is propagated through the simulated signal samples as a function of η^γ and p_T^γ . The uncertainty associated with the description of the photon energy scale in the simulation is found to be less than 0.3% of the three-body invariant mass while the uncertainty associated with the photon energy resolution is found to be negligible relative to the overall three-body invariant mass resolution. Similarly, the systematic uncertainty associated with the track momentum measurement is found to be negligible.

The uncertainty on the shape of the inclusive multijet and photon + jet background is estimated through the study of variations in the background modeling procedure. The shape of the background model is allowed to vary around the nominal shape within an envelope associated with shifts in the $p_T^{K^+K^-}$ distribution, tilts of the $\Delta\phi(K^+K^-, \gamma)$ distribution, and by neglecting the weakest correlation accounted for in the nominal background model.

Results are compared to background and signal predictions using an unbinned maximum-likelihood fit to the $m_{K^+K^-\gamma}$ distribution. The fit uses the selected events with $m_{K^+K^-\gamma} < 300$ GeV. The systematic uncertainties described above result in a 3% deterioration of the sensitivity to the $H \rightarrow \phi\gamma$ decay. For the Z boson decay the reduction is larger, 13%, mainly due to the systematic uncertainty in the background shape. The expected and observed numbers of background events within the $m_{K^+K^-\gamma}$ ranges relevant to the Higgs and Z boson signals are shown in Table I.

TABLE II. Expected and observed branching fraction limits at 95% C.L. for 2.7 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV. The $\pm 1\sigma$ intervals of the expected limits are also given.

Branching fraction limit (95% C.L.)	Expected	Observed
$\mathcal{B}(H \rightarrow \phi\gamma)[10^{-3}]$	$1.5^{+0.7}_{-0.4}$	1.4
$\mathcal{B}(Z \rightarrow \phi\gamma)[10^{-6}]$	$4.4^{+2.0}_{-1.2}$	8.3

On the basis of the observed data, upper limits are set on the branching fractions for the Higgs and Z boson decays to $\phi\gamma$ using the CL_s modified frequentist formalism [44] with the profile-likelihood ratio test statistic [45]. The result of the background-only fit is shown in Fig. 3; a small excess of two standard deviations is observed in the Z boson mass region, estimated using the asymptotic approximation for the distribution of the test statistic. The expected SM production cross section is assumed for the Higgs boson while the ATLAS measurement of the inclusive Z boson cross section is used for the Z boson signal [30]. The results are summarized in Table II. The observed 95% confidence level (C.L.) upper limits on the branching fractions for $H \rightarrow \phi\gamma$ and $Z \rightarrow \phi\gamma$ decays are around 600 and 700 times the expected SM branching fractions, respectively.

In conclusion, a search for the decay of Higgs or Z bosons to $\phi\gamma$ has been performed with a pp collision data sample at $\sqrt{s} = 13$ TeV corresponding to an integrated luminosity of 2.7 fb^{-1} collected with the ATLAS detector at the LHC. No significant excess of events is observed above the background. Upper limits at the 95% C.L. are set on the branching fractions for the decay of the 125 GeV SM Higgs boson and the Z boson to $\phi\gamma$. The obtained limits are $\mathcal{B}(H \rightarrow \phi\gamma) < 1.4 \times 10^{-3}$ and $\mathcal{B}(Z \rightarrow \phi\gamma) < 8.3 \times 10^{-6}$.

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently. We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR (Ministry of Industry and Trade) and VSC CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS, CEA-DSM/IRFU, France; GNSF, Georgia; BMBF, HGF (Helmholtz Association), and MPG, Germany; GSRT, Greece; RGC, Hong Kong SAR, China; ISF, I-CORE and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal; MNE/IFA, Romania; MES of Russia and NRC KI, Russian Federation; JINR; MESTD (Ministry of Education, Science and Technological Development), Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MINECO, Spain; SRC and

Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, the Canada Council, CANARIE, CRC, Compute Canada, FQRNT, and the Ontario Innovation Trust, Canada; EPLANET, ERC, FP7, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex and Idex, ANR, Région Auvergne and Fondation Partager le Savoir, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF; BSF, GIF and Minerva, Israel; BRF (Bergen Research Foundation), Norway; Generalitat de Catalunya, Generalitat Valenciana, Spain; the Royal Society and Leverhulme Trust, United Kingdom. The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [46].

- [1] ATLAS Collaboration, Observation of a new particle in the search for the standard model Higgs boson with the ATLAS detector at the LHC, *Phys. Lett. B* **716**, 1 (2012).
- [2] CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, *Phys. Lett. B* **716**, 30 (2012).
- [3] A. L. Kagan, G. Perez, F. Petriello, Y. Soreq, S. Stoynev, and J. Zupan, An Exclusive Window onto Higgs Yukawa Couplings, *Phys. Rev. Lett.* **114**, 101802 (2015).
- [4] M. König and M. Neubert, Exclusive radiative Higgs decays as probes of light-quark Yukawa couplings, *J. High Energy Phys.* **08** (2015) 012.
- [5] G. Perez, Y. Soreq, E. Stamou, and K. Tobioka, Prospects for measuring the Higgs boson coupling to light quarks, *Phys. Rev. D* **93**, 013001 (2016).
- [6] G. D'Ambrosio, G. F. Giudice, G. Isidori, and A. Strumia, Minimal flavor violation: An effective field theory approach, *Nucl. Phys.* **B645**, 155 (2002).
- [7] C. D. Froggatt and H. B. Nielsen, Hierarchy of quark masses, Cabibbo angles and CP violation, *Nucl. Phys.* **B147**, 277 (1979).
- [8] G. F. Giudice and O. Lebedev, Higgs-dependent Yukawa couplings, *Phys. Lett. B* **665**, 79 (2008).
- [9] L. Randall and R. Sundrum, Large Mass Hierarchy from a Small Extra Dimension, *Phys. Rev. Lett.* **83**, 3370 (1999).
- [10] M. J. Dugan, H. Georgi, and D. B. Kaplan, Anatomy of a composite Higgs model, *Nucl. Phys.* **B254**, 299 (1985).
- [11] M. Doroshenko *et al.*, Vector quarkonium in decays of heavy Higgs particles, *Yad. Fiz.* **46**, 864 (1987).
- [12] G. T. Bodwin, F. Petriello, S. Stoynev, and M. Velasco, Higgs boson decays to quarkonia and the $H\bar{c}c$ coupling, *Phys. Rev. D* **88**, 053003 (2013).
- [13] G. T. Bodwin, H. S. Chung, J.-H. Ee, J. Lee, and F. Petriello, Relativistic corrections to Higgs-boson decays to quarkonia, *Phys. Rev. D* **90**, 113010 (2014).
- [14] ATLAS Collaboration, Search for Higgs and Z Boson Decays to $J/\psi\gamma$ and $\Upsilon(nS)\gamma$ with the ATLAS Detector, *Phys. Rev. Lett.* **114**, 121801 (2015).
- [15] CMS Collaboration, Search for a Higgs boson decaying into $\gamma^*\gamma \rightarrow \ell\ell\gamma$ with low dilepton mass in pp collisions at $\sqrt{s} = 8$ TeV, *Phys. Lett. B* **753**, 341 (2016).
- [16] T.-C. Huang and F. Petriello, Rare exclusive decays of the Z boson revisited, *Phys. Rev. D* **92**, 014007 (2015).
- [17] Y. Grossman, M. König, and M. Neubert, Exclusive radiative decays of W and Z Bosons in QCD factorization, *J. High Energy Phys.* **04** (2015) 101.
- [18] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, *J. Instrum.* **3**, S08003 (2008).
- [19] P. Nason, A New method for combining NLO QCD with shower Monte Carlo algorithms, *J. High Energy Phys.* **11** (2004) 040.
- [20] S. Frixione, P. Nason, and C. Oleari, Matching NLO QCD computations with parton shower simulations: The POWHEG method, *J. High Energy Phys.* **11** (2007) 070.
- [21] S. Alioli, P. Nason, C. Oleari, and E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: The POWHEG BOX, *J. High Energy Phys.* **06** (2010) 043.
- [22] S. Alioli, P. Nason, C. Oleari, and E. Re, NLO Higgs boson production via gluon fusion matched with shower in POWHEG, *J. High Energy Phys.* **04** (2009) 002.
- [23] P. Nason and C. Oleari, NLO Higgs boson production via vector-boson fusion matched with shower in POWHEG, *J. High Energy Phys.* **02** (2010) 037.
- [24] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, and C.-P. Yuan, New parton distributions for collider physics, *Phys. Rev. D* **82**, 074024 (2010).
- [25] T. Sjöstrand, S. Mrenna, and P. Z. Skands, A brief introduction to PYTHIA 8.1, *Comput. Phys. Commun.* **178**, 852 (2008).
- [26] T. Sjöstrand, S. Mrenna, and P. Z. Skands, PYTHIA 6.4 physics and manual, *J. High Energy Phys.* **05** (2006) 026.
- [27] R. D. Ball *et al.*, Parton distributions with LHC data, *Nucl. Phys.* **B867**, 244 (2013).
- [28] LHC Higgs Cross Section Working Group, Handbook of LHC Higgs Cross Sections: 3. Higgs Properties, CERN-2013-004 (CERN, Geneva, 2013), [arXiv:1307.1347](https://arxiv.org/abs/1307.1347).
- [29] J. Pumplin, D. R. Stump, J. Huston, H.-L. Lai, P. Nadolsky, and W.-K. Tung, New generation of parton distributions with uncertainties from global QCD analysis, *J. High Energy Phys.* **07** (2002) 012.
- [30] ATLAS Collaboration, Measurement of W^\pm and Z-boson production cross sections in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Phys. Lett. B* **759**, 601 (2016).
- [31] ATLAS Collaboration, Measurement of the Z/γ^* boson transverse momentum distribution in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, *J. High Energy Phys.* **09** (2014) 145.

- [32] S. Agostinelli *et al.*, GEANT4: a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [33] ATLAS Collaboration, The ATLAS simulation infrastructure, *Eur. Phys. J. C* **70**, 823 (2010).
- [34] K. A. Olive *et al.*, Review of particle physics, *Chin. Phys. C* **38**, 090001 (2014).
- [35] ATLAS Collaboration, ATL-PHYS-PUB-2015-051, 2015, <http://cds.cern.ch/record/2110140>.
- [36] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z axis along the beam pipe. The x axis points from the IP to the center of the LHC ring, and the y axis points upward. Cylindrical coordinates are used in the transverse plane, with $\Delta\phi$ being the difference in azimuthal angles around the z axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$.
- [37] ATLAS Collaboration, Measurement of the photon identification efficiencies with the ATLAS detector using LHC Run-1 data, [arXiv:1606.01813](https://arxiv.org/abs/1606.01813).
- [38] ATLAS Collaboration, Measurement of the inclusive isolated prompt photon cross section in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, *Phys. Rev. D* **83**, 052005 (2011).
- [39] J. P. Lees *et al.* (BABAR Collaboration), Measurement of the $D^*(2010)^+$ natural line width and the $D^*(2010)^+ - D^0$ mass difference, *Phys. Rev. D* **88**, 052003 (2013); **88**, 079902(E) (2013).
- [40] K. S. Cranmer, Kernel estimation in high-energy physics, *Comput. Phys. Commun.* **136**, 198 (2001).
- [41] ATLAS Collaboration, ATLAS-CONF-2012-048, 2012, <http://cds.cern.ch/record/1450089>.
- [42] ATLAS Collaboration, Improved luminosity determination in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector at the LHC, *Eur. Phys. J. C* **73**, 2518 (2013).
- [43] ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using LHC Run 1 data, *Eur. Phys. J. C* **74**, 3071 (2014).
- [44] A. L. Read, Presentation of search results: The CLs technique, *J. Phys. G* **28**, 2693 (2002).
- [45] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, *Eur. Phys. J. C* **71**, 1554 (2011); **73**, 2501(E) (2013).
- [46] ATLAS Collaboration, ATL-GEN-PUB-2016-002, 2016, <http://cds.cern.ch/record/2202407>.

M. Aaboud,^{135d} G. Aad,⁸⁶ B. Abbott,¹¹³ J. Abdallah,⁶⁴ O. Abidinov,¹² B. Abeloos,¹¹⁷ R. Aben,¹⁰⁷ O. S. AbouZeid,¹³⁷ N. L. Abraham,¹⁴⁹ H. Abramowicz,¹⁵³ H. Abreu,¹⁵² R. Abreu,¹¹⁶ Y. Abulaiti,^{146a,146b} B. S. Acharya,^{163a,163b,b} L. Adamczyk,^{40a} D. L. Adams,²⁷ J. Adelman,¹⁰⁸ S. Adomeit,¹⁰⁰ T. Adye,¹³¹ A. A. Affolder,⁷⁵ T. Agatonovic-Jovin,¹⁴ J. Agricola,⁵⁶ J. A. Aguilar-Saavedra,^{126a,126f} S. P. Ahlen,²⁴ F. Ahmadov,^{66,c} G. Aielli,^{133a,133b} H. Akerstedt,^{146a,146b} T. P. A. Åkesson,⁸² A. V. Akimov,⁹⁶ G. L. Alberghi,^{22a,22b} J. Albert,¹⁶⁸ S. Albrand,⁵⁷ M. J. Alconada Verzini,⁷² M. Aleksa,³² I. N. Aleksandrov,⁶⁶ C. Alexa,^{28b} G. Alexander,¹⁵³ T. Alexopoulos,¹⁰ M. Alhroob,¹¹³ B. Ali,¹²⁸ M. Aliev,^{74a,74b} G. Alimonti,^{92a} J. Alison,³³ S. P. Alkire,³⁷ B. M. M. Allbrooke,¹⁴⁹ B. W. Allen,¹¹⁶ P. P. Allport,¹⁹ A. Aloisio,^{104a,104b} A. Alonso,³⁸ F. Alonso,⁷² C. Alpigiani,¹³⁸ M. Alstary,⁸⁶ B. Alvarez Gonzalez,³² D. Álvarez Piqueras,¹⁶⁶ M. G. Alviggi,^{104a,104b} B. T. Amadio,¹⁶ K. Amako,⁶⁷ Y. Amaral Coutinho,^{26a} C. Amelung,²⁵ D. Amidei,⁹⁰ S. P. Amor Dos Santos,^{126a,126c} A. Amorim,^{126a,126b} S. Amoroso,³² G. Amundsen,²⁵ C. Anastopoulos,¹³⁹ L. S. Ancu,⁵¹ N. Andari,¹⁹ T. Andeen,¹¹ C. F. Anders,^{59b} G. Anders,³² J. K. Anders,⁷⁵ K. J. Anderson,³³ A. Andreazza,^{92a,92b} V. Andrei,^{59a} S. Angelidakis,⁹ I. Angelozzi,¹⁰⁷ P. Anger,⁴⁶ A. Angerami,³⁷ F. Anghinolfi,³² A. V. Anisenkov,^{109,d} N. Anjos,¹³ A. Annovi,^{124a,124b} C. Antel,^{59a} M. Antonelli,⁴⁹ A. Antonov,^{98,a} F. Anulli,^{132a} M. Aoki,⁶⁷ L. Aperio Bella,¹⁹ G. Arabidze,⁹¹ Y. Arai,⁶⁷ J. P. Araque,^{126a} A. T. H. Arce,⁴⁷ F. A. Arduh,⁷² J.-F. Arguin,⁹⁵ S. Argyropoulos,⁶⁴ M. Arik,^{20a} A. J. Armbruster,¹⁴³ L. J. Armitage,⁷⁷ O. Arnaez,³² H. Arnold,⁵⁰ M. Arratia,³⁰ O. Arslan,²³ A. Artamonov,⁹⁷ G. Artoni,¹²⁰ S. Artz,⁸⁴ S. Asai,¹⁵⁵ N. Asbah,⁴⁴ A. Ashkenazi,¹⁵³ B. Åsman,^{146a,146b} L. Asquith,¹⁴⁹ K. Assamagan,²⁷ R. Astalos,^{144a} M. Atkinson,¹⁶⁵ N. B. Atlay,¹⁴¹ K. Augsten,¹²⁸ G. Avolio,³² B. Axen,¹⁶ M. K. Ayoub,¹¹⁷ G. Azuelos,^{95,e} M. A. Baak,³² A. E. Baas,^{59a} M. J. Baca,¹⁹ H. Bachacou,¹³⁶ K. Bachas,^{74a,74b} M. Backes,¹⁴⁸ M. Backhaus,³² P. Bagiacchi,^{132a,132b} P. Bagnaia,^{132a,132b} Y. Bai,^{35a} J. T. Baines,¹³¹ O. K. Baker,¹⁷⁵ E. M. Baldin,^{109,d} P. Balek,¹⁷¹ T. Balestri,¹⁴⁸ F. Balli,¹³⁶ W. K. Balunas,¹²² E. Banas,⁴¹ Sw. Banerjee,^{172,f} A. A. E. Bannoura,¹⁷⁴ L. Barak,³² E. L. Barberio,⁸⁹ D. Barberis,^{52a,52b} M. Barbero,⁸⁶ T. Barillari,¹⁰¹ M.-S. Barisits,³² T. Barklow,¹⁴³ N. Barlow,³⁰ S. L. Barnes,⁸⁵ B. M. Barnett,¹³¹ R. M. Barnett,¹⁶ Z. Barnovska,⁵ A. Baroncelli,^{134a} G. Barone,²⁵ A. J. Barr,¹²⁰ L. Barranco Navarro,¹⁶⁶ F. Barreiro,⁸³ J. Barreiro Guimarães da Costa,^{35a} R. Bartoldus,¹⁴³ A. E. Barton,⁷³ P. Bartos,^{144a} A. Basalaeu,¹²³ A. Bassalat,¹¹⁷ R. L. Bates,⁵⁵ S. J. Batista,¹⁵⁸ J. R. Batley,³⁰ M. Battaglia,¹³⁷ M. Bauce,^{132a,132b} F. Bauer,¹³⁶ H. S. Bawa,^{143,g} J. B. Beacham,¹¹¹ M. D. Beattie,⁷³ T. Beau,⁸¹ P. H. Beauchemin,¹⁶¹ P. Bechtel,²³ H. P. Beck,^{18,h} K. Becker,¹²⁰ M. Becker,⁸⁴ M. Beckingham,¹⁶⁹ C. Becot,¹¹⁰ A. J. Beddall,^{20d} A. Beddall,^{20b} V. A. Bednyakov,⁶⁶ M. Bedognetti,¹⁰⁷ C. P. Bee,¹⁴⁸ L. J. Beemster,¹⁰⁷ T. A. Beermann,³² M. Begel,²⁷ J. K. Behr,⁴⁴ C. Belanger-Champagne,⁸⁸ A. S. Bell,⁷⁹ G. Bella,¹⁵³ L. Bellagamba,^{22a} A. Bellerive,³¹

- M. Bellomo,⁸⁷ K. Belotskiy,⁹⁸ O. Beltramello,³² N. L. Belyaev,⁹⁸ O. Benary,¹⁵³ D. Benckekroun,^{135a} M. Bender,¹⁰⁰ K. Bendtz,^{146a,146b} N. Benekos,¹⁰ Y. Benhammou,¹⁵³ E. Benhar Noccioli,¹⁷⁵ J. Benitez,⁶⁴ D. P. Benjamin,⁴⁷ J. R. Bensinger,²⁵ S. Bentvelsen,¹⁰⁷ L. Beresford,¹²⁰ M. Beretta,⁴⁹ D. Berge,¹⁰⁷ E. Bergeas Kuutmann,¹⁶⁴ N. Berger,⁵ J. Beringer,¹⁶ S. Berlendis,⁵⁷ N. R. Bernard,⁸⁷ C. Bernius,¹¹⁰ F. U. Bernlochner,²³ T. Berry,⁷⁸ P. Berta,¹²⁹ C. Bertella,⁸⁴ G. Bertoli,^{146a,146b} F. Bertolucci,^{124a,124b} I. A. Bertram,⁷³ C. Bertsche,⁴⁴ D. Bertsche,¹¹³ G. J. Besjes,³⁸ O. Bessidskaia Bylund,^{146a,146b} M. Bessner,⁴⁴ N. Besson,¹³⁶ C. Betancourt,⁵⁰ A. Bethani,⁵⁷ S. Bethke,¹⁰¹ A. J. Bevan,⁷⁷ R. M. Bianchi,¹²⁵ L. Bianchini,²⁵ M. Bianco,³² O. Biebel,¹⁰⁰ D. Biedermann,¹⁷ R. Bielski,⁸⁵ N. V. Biesuz,^{124a,124b} M. Biglietti,^{134a} J. Bilbao De Mendizabal,⁵¹ T. R. V. Billoud,⁹⁵ H. Bilokon,⁴⁹ M. Bindi,⁵⁶ S. Binet,¹¹⁷ A. Bingul,^{20b} C. Bini,^{132a,132b} S. Biondi,^{22a,22b} T. Bisanz,⁵⁶ D. M. Bjergaard,⁴⁷ C. W. Black,¹⁵⁰ J. E. Black,¹⁴³ K. M. Black,²⁴ D. Blackburn,¹³⁸ R. E. Blair,⁶ J.-B. Blanchard,¹³⁶ T. Blazek,^{144a} I. Bloch,⁴⁴ C. Blocker,²⁵ W. Blum,^{84a} U. Blumenschein,⁵⁶ S. Blunier,^{34a} G. J. Bobbink,¹⁰⁷ V. S. Bobrovnikov,^{109,d} S. S. Bocchetta,⁸² A. Bocci,⁴⁷ C. Bock,¹⁰⁰ M. Boehler,⁵⁰ D. Boerner,¹⁷⁴ J. A. Bogaerts,³² D. Bogavac,¹⁴ A. G. Bogdanchikov,¹⁰⁹ C. Bohm,^{146a} V. Boisvert,⁷⁸ P. Bokan,¹⁴ T. Bold,^{40a} A. S. Boldyrev,^{163a,163c} M. Bomben,⁸¹ M. Bona,⁷⁷ M. Boonekamp,¹³⁶ A. Borisov,¹³⁰ G. Borissov,⁷³ J. Bortfeldt,³² D. Bortoletto,¹²⁰ V. Bortolotto,^{61a,61b,61c} K. Bos,¹⁰⁷ D. Boscherini,^{22a} M. Bosman,¹³ J. D. Bossio Sola,²⁹ J. Boudreau,¹²⁵ J. Bouffard,² E. V. Bouhova-Thacker,⁷³ D. Boumediene,³⁶ C. Bourdarios,¹¹⁷ S. K. Boutle,⁵⁵ A. Boveia,³² J. Boyd,³² I. R. Boyko,⁶⁶ J. Bracinik,¹⁹ A. Brandt,⁸ G. Brandt,⁵⁶ O. Brandt,^{59a} U. Bratzler,¹⁵⁶ B. Brau,⁸⁷ J. E. Brau,¹¹⁶ H. M. Braun,^{174,a} W. D. Breden Madden,⁵⁵ K. Brendlinger,¹²² A. J. Brennan,⁸⁹ L. Brenner,¹⁰⁷ R. Brenner,¹⁶⁴ S. Bressler,¹⁷¹ T. M. Bristow,⁴⁸ D. Britton,⁵⁵ D. Britzger,⁴⁴ F. M. Brochu,³⁰ I. Brock,²³ R. Brock,⁹¹ G. Brooijmans,³⁷ T. Brooks,⁷⁸ W. K. Brooks,^{34b} J. Brosamer,¹⁶ E. Brost,¹⁰⁸ J. H. Broughton,¹⁹ P. A. Bruckman de Renstrom,⁴¹ D. Bruncko,^{144b} R. Bruneliere,⁵⁰ A. Bruni,^{22a} G. Bruni,^{22a} L. S. Bruni,¹⁰⁷ BH Brunt,³⁰ M. Bruschi,^{22a} N. Bruscino,²³ P. Bryant,³³ L. Bryngemark,⁸² T. Buanes,¹⁵ Q. Buat,¹⁴² P. Buchholz,¹⁴¹ A. G. Buckley,⁵⁵ I. A. Budagov,⁶⁶ F. Buehrer,⁵⁰ M. K. Bugge,¹¹⁹ O. Bulekov,⁹⁸ D. Bullock,⁸ H. Burckhart,³² S. Burdin,⁷⁵ C. D. Burgard,⁵⁰ B. Burghgrave,¹⁰⁸ K. Burka,⁴¹ S. Burke,¹³¹ I. Burmeister,⁴⁵ J. T. P. Burr,¹²⁰ E. Busato,³⁶ D. Büscher,⁵⁰ V. Büscher,⁸⁴ P. Bussey,⁵⁵ J. M. Butler,²⁴ C. M. Buttar,⁵⁵ J. M. Butterworth,⁷⁹ P. Butti,¹⁰⁷ W. Buttinger,²⁷ A. Buzatu,⁵⁵ A. R. Buzykaev,^{109,d} S. Cabrera Urbán,¹⁶⁶ D. Caforio,¹²⁸ V. M. Cairo,^{39a,39b} O. Cakir,^{4a} N. Calace,⁵¹ P. Calafiura,¹⁶ A. Calandri,⁸⁶ G. Calderini,⁸¹ P. Calfayan,¹⁰⁰ G. Callea,^{39a,39b} L. P. Caloba,^{26a} S. Calvente Lopez,⁸³ D. Calvet,³⁶ S. Calvet,³⁶ T. P. Calvet,⁸⁶ R. Camacho Toro,³³ S. Camarda,³² P. Camarri,^{133a,133b} D. Cameron,¹¹⁹ R. Caminal Armadans,¹⁶⁵ C. Camincher,⁵⁷ S. Campana,³² M. Campanelli,⁷⁹ A. Camplani,^{92a,92b} A. Campoverde,¹⁴¹ V. Canale,^{104a,104b} A. Canepa,^{159a} M. Cano Bret,^{35e} J. Cantero,¹¹⁴ R. Cantrill,^{126a} T. Cao,⁴² M. D. M. Capeans Garrido,³² I. Caprini,^{28b} M. Caprini,^{28b} M. Capua,^{39a,39b} R. Caputo,⁸⁴ R. M. Carbone,³⁷ R. Cardarelli,^{133a} F. Cardillo,⁵⁰ I. Carli,¹²⁹ T. Carli,³² G. Carlino,^{104a} L. Carminati,^{92a,92b} S. Caron,¹⁰⁶ E. Carquin,^{34b} G. D. Carrillo-Montoya,³² J. R. Carter,³⁰ J. Carvalho,^{126a,126c} D. Casadei,¹⁹ M. P. Casado,^{13,i} M. Casolino,¹³ D. W. Casper,¹⁶² E. Castaneda-Miranda,^{145a} R. Castelijns,¹⁰⁷ A. Castelli,¹⁰⁷ V. Castillo Gimenez,¹⁶⁶ N. F. Castro,^{126a,j} A. Catinaccio,³² J. R. Catmore,¹¹⁹ A. Cattai,³² J. Caudron,²³ V. Cavaliere,¹⁶⁵ E. Cavallaro,¹³ D. Cavalli,^{92a} M. Cavalli-Sforza,¹³ V. Cavasinni,^{124a,124b} F. Ceradini,^{134a,134b} L. Cerda Alberich,¹⁶⁶ B. C. Cerio,⁴⁷ A. S. Cerqueira,^{26b} A. Cerri,¹⁴⁹ L. Cerrito,^{133a,133b} F. Cerutti,¹⁶ M. Cerv,³² A. Cervelli,¹⁸ S. A. Cetin,^{20c} A. Chafaq,^{135a} D. Chakraborty,¹⁰⁸ S. K. Chan,⁵⁸ Y. L. Chan,^{61a} P. Chang,¹⁶⁵ J. D. Chapman,³⁰ D. G. Charlton,¹⁹ A. Chatterjee,⁵¹ C. C. Chau,¹⁵⁸ C. A. Chavez Barajas,¹⁴⁹ S. Che,¹¹¹ S. Cheatham,⁷³ A. Chegwidan,⁹¹ S. Chekanov,⁶ S. V. Chekulaev,^{159a} G. A. Chelkov,^{66,k} M. A. Chelstowska,⁹⁰ C. Chen,⁶⁵ H. Chen,²⁷ K. Chen,¹⁴⁸ S. Chen,^{35c} S. Chen,¹⁵⁵ X. Chen,^{35f} Y. Chen,⁶⁸ H. C. Cheng,⁹⁰ H. J. Cheng,^{35a} Y. Cheng,³³ A. Cheplakov,⁶⁶ E. Cheremushkina,¹³⁰ R. Cherkaoui El Moursli,^{135e} V. Chernyatin,^{27,a} E. Cheu,⁷ L. Chevalier,¹³⁶ V. Chiarella,⁴⁹ G. Chiarelli,^{124a,124b} G. Chiodini,^{74a} A. S. Chisholm,¹⁹ A. Chitan,^{28b} M. V. Chizhov,⁶⁶ K. Choi,⁶² A. R. Chomont,³⁶ S. Chouridou,⁹ B. K. B. Chow,¹⁰⁰ V. Christodoulou,⁷⁹ D. Chromek-Burckhart,³² J. Chudoba,¹²⁷ A. J. Chuinard,⁸⁸ J. J. Chwastowski,⁴¹ L. Chytka,¹¹⁵ G. Ciapetti,^{132a,132b} A. K. Ciftci,^{4a} D. Cinca,⁴⁵ V. Cindro,⁷⁶ I. A. Cioara,²³ C. Ciocca,^{22a,22b} A. Ciochio,¹⁶ F. Ciotto,^{104a,104b} Z. H. Citron,¹⁷¹ M. Citterio,^{92a} M. Ciubancan,^{28b} A. Clark,⁵¹ B. L. Clark,⁵⁸ M. R. Clark,³⁷ P. J. Clark,⁴⁸ R. N. Clarke,¹⁶ C. Clement,^{146a,146b} Y. Coadou,⁸⁶ M. Cobal,^{163a,163c} A. Coccaro,⁵¹ J. Cochran,⁶⁵ L. Colasurdo,¹⁰⁶ B. Cole,³⁷ A. P. Colijn,¹⁰⁷ J. Collot,⁵⁷ T. Colombo,³² G. Compostella,¹⁰¹ P. Conde Muño,^{126a,126b} E. Coniavitis,⁵⁰ S. H. Connell,^{145b} I. A. Connolly,⁷⁸ V. Consorti,⁵⁰ S. Constantinescu,^{28b} G. Conti,³² F. Conventi,^{104a,l} M. Cooke,¹⁶ B. D. Cooper,⁷⁹ A. M. Cooper-Sarkar,¹²⁰ K. J. R. Cormier,¹⁵⁸ T. Cornelissen,¹⁷⁴ M. Corradi,^{132a,132b} F. Corriveau,^{88,m} A. Corso-Radu,¹⁶² A. Cortes-Gonzalez,³² G. Cortiana,¹⁰¹ G. Costa,^{92a} M. J. Costa,¹⁶⁶ D. Costanzo,¹³⁹ G. Cottin,³⁰ G. Cowan,⁷⁸ B. E. Cox,⁸⁵ K. Cranmer,¹¹⁰ S. J. Crawley,⁵⁵ G. Cree,³¹ S. Crépe-Renaudin,⁵⁷ F. Crescioli,⁸¹ W. A. Cribbs,^{146a,146b} M. Crispin Ortuzar,¹²⁰

- M. Cristinziani,²³ V. Croft,¹⁰⁶ G. Crosetti,^{39a,39b} A. Cueto,⁸³ T. Cuhadar Donszelmann,¹³⁹ J. Cummings,¹⁷⁵ M. Curatolo,⁴⁹ J. Cúth,⁸⁴ H. Czirr,¹⁴¹ P. Czodrowski,³ G. D'amen,^{22a,22b} S. D'Auria,⁵⁵ M. D'Onofrio,⁷⁵
- M. J. Da Cunha Sargedas De Sousa,^{126a,126b} C. Da Via,⁸⁵ W. Dabrowski,^{40a} T. Dado,^{144a} T. Dai,⁹⁰ O. Dale,¹⁵ F. Dallaire,⁹⁵ C. Dallapiccola,⁸⁷ M. Dam,³⁸ J. R. Dandoy,³³ N. P. Dang,⁵⁰ A. C. Daniells,¹⁹ N. S. Dann,⁸⁵ M. Danninger,¹⁶⁷
- M. Dano Hoffmann,¹³⁶ V. Dao,⁵⁰ G. Darbo,^{52a} S. Darmora,⁸ J. Dassoulas,³ A. Dattagupta,⁶² W. Davey,²³ C. David,¹⁶⁸ T. Davidek,¹²⁹ M. Davies,¹⁵³ P. Davison,⁷⁹ E. Dawe,⁸⁹ I. Dawson,¹³⁹ R. K. Daya-Ishmukhametova,⁸⁷ K. De,⁸
- R. de Asmundis,^{104a} A. De Benedetti,¹¹³ S. De Castro,^{22a,22b} S. De Cecco,⁸¹ N. De Groot,¹⁰⁶ P. de Jong,¹⁰⁷ H. De la Torre,⁸³ F. De Lorenzi,⁶⁵ A. De Maria,⁵⁶ D. De Pedis,^{132a} A. De Salvo,^{132a} U. De Sanctis,¹⁴⁹ A. De Santo,¹⁴⁹
- J. B. De Vivie De Regie,¹¹⁷ W. J. Dearnaley,⁷³ R. Debbe,²⁷ C. Debenedetti,¹³⁷ D. V. Dedovich,⁶⁶ N. Dehghanian,³ I. Deigaard,¹⁰⁷ M. Del Gaudio,^{39a,39b} J. Del Peso,⁸³ T. Del Prete,^{124a,124b} D. Delgove,¹¹⁷ F. Deliot,¹³⁶ C. M. Delitzsch,⁵¹
- A. Dell'Acqua,³² L. Dell'Asta,²⁴ M. Dell'Orso,^{124a,124b} M. Della Pietra,^{104a,1} D. della Volpe,⁵¹ M. Delmastro,⁵ P. A. Delsart,⁵⁷ D. A. DeMarco,¹⁵⁸ S. Demers,¹⁷⁵ M. Demichev,⁶⁶ A. Demilly,⁸¹ S. P. Denisov,¹³⁰ D. Denysiuk,¹³⁶ D. Derendarz,⁴¹
- J. E. Derkaoui,^{135d} F. Derue,⁸¹ P. Dervan,⁷⁵ K. Desch,²³ C. Deterre,⁴⁴ K. Dette,⁴⁵ P. O. Deviveiros,³² A. Dewhurst,¹³¹ S. Dhaliwal,²⁵ A. Di Ciaccio,^{133a,133b} L. Di Ciaccio,⁵ W. K. Di Clemente,¹²² C. Di Donato,^{132a,132b} A. Di Girolamo,³²
- B. Di Girolamo,³² B. Di Micco,^{134a,134b} R. Di Nardo,³² A. Di Simone,⁵⁰ R. Di Sipio,¹⁵⁸ D. Di Valentino,³¹ C. Diaconu,⁸⁶ M. Diamond,¹⁵⁸ F. A. Dias,⁴⁸ M. A. Diaz,^{34a} E. B. Diehl,⁹⁰ J. Dietrich,¹⁷ S. Diglio,⁸⁶ A. Dimitrievska,¹⁴ J. Dingfelder,²³
- P. Dita,^{28b} S. Dita,^{28b} F. Dittus,³² F. Djama,⁸⁶ T. Djobava,^{53b} J. I. Djuvsland,^{59a} M. A. B. do Vale,^{26c} D. Dobos,³² M. Dobre,^{28b} C. Doglioni,⁸² J. Dolejsi,¹²⁹ Z. Dolezal,¹²⁹ M. Donadelli,^{26d} S. Donati,^{124a,124b} P. Dondero,^{121a,121b} J. Donini,³⁶ J. Dopke,¹³¹
- A. Doria,^{104a} M. T. Dova,⁷² A. T. Doyle,⁵⁵ E. Drechsler,⁵⁶ M. Dris,¹⁰ Y. Du,^{35d} J. Duarte-Campderros,¹⁵³ E. Duchovni,¹⁷¹ G. Duckeck,¹⁰⁰ O. A. Ducu,⁹⁵ⁿ D. Duda,¹⁰⁷ A. Dudarev,³² A. Chr. Dudder,⁸⁴ E. M. Duffield,¹⁶ L. Duflot,¹¹⁷ M. Dührssen,³²
- M. Dumancic,¹⁷¹ M. Dunford,^{59a} H. Duran Yildiz,^{4a} M. Düren,⁵⁴ A. Durglishvili,^{53b} D. Duschinger,⁴⁶ B. Dutta,⁴⁴ M. Dyndal,⁴⁴ C. Eckardt,⁴⁴ K. M. Ecker,¹⁰¹ R. C. Edgar,⁹⁰ N. C. Edwards,⁴⁸ T. Eifert,³² G. Eigen,¹⁵ K. Einsweiler,¹⁶
- T. Ekelof,¹⁶⁴ M. El Kacimi,^{135c} V. Ellajosyula,⁸⁶ M. Ellert,¹⁶⁴ S. Elles,⁵ F. Ellinghaus,¹⁷⁴ A. A. Elliot,¹⁶⁸ N. Ellis,³² J. Elmsheuser,²⁷ M. Elsing,³² D. Emelianov,¹³¹ Y. Enari,¹⁵⁵ O. C. Endner,⁸⁴ J. S. Ennis,¹⁶⁹ J. Erdmann,⁴⁵ A. Ereditato,¹⁸
- G. Ernis,¹⁷⁴ J. Ernst,² M. Ernst,²⁷ S. Errede,¹⁶⁵ E. Ertel,⁸⁴ M. Escalier,¹¹⁷ H. Esch,⁴⁵ C. Escobar,¹²⁵ B. Esposito,⁴⁹ A. I. Etiennev,¹³⁶ E. Etzion,¹⁵³ H. Evans,⁶² A. Ezhilov,¹²³ F. Fabbri,^{22a,22b} L. Fabbri,^{22a,22b} G. Facini,³³ R. M. Fakhrutdinov,¹³⁰
- S. Falciano,^{132a} R. J. Falla,⁷⁹ J. Faltova,³² Y. Fang,^{35a} M. Fanti,^{92a,92b} A. Farbin,⁸ A. Farilla,^{134a} C. Farina,¹²⁵ E. M. Farina,^{121a,121b} T. Farooque,¹³ S. Farrell,¹⁶ S. M. Farrington,¹⁶⁹ P. Farthouat,³² F. Fassi,^{135e} P. Fassnacht,³²
- D. Fassouliotis,⁹ M. Faucci Giannelli,⁷⁸ A. Favareto,^{52a,52b} W. J. Fawcett,¹²⁰ L. Fayard,¹¹⁷ O. L. Fedin,^{123,o} W. Fedorko,¹⁶⁷ S. Feigl,¹¹⁹ L. Feligioni,⁸⁶ C. Feng,^{35d} E. J. Feng,³² H. Feng,⁹⁰ A. B. Fenyuk,¹³⁰ L. Feremenga,⁸ P. Fernandez Martinez,¹⁶⁶
- S. Fernandez Perez,¹³ J. Ferrando,⁵⁵ A. Ferrari,¹⁶⁴ P. Ferrari,¹⁰⁷ R. Ferrari,^{121a} D. E. Ferreira de Lima,^{59b} A. Ferrer,¹⁶⁶ D. Ferrere,⁵¹ C. Ferretti,⁹⁰ A. Ferretto Parodi,^{52a,52b} F. Fiedler,⁸⁴ A. Filipčič,⁷⁶ M. Filipuzzi,⁴⁴ F. Filthaut,¹⁰⁶
- M. Fincke-Keeler,¹⁶⁸ K. D. Finelli,¹⁵⁰ M. C. N. Fiolhais,^{126a,126c} L. Fiorini,¹⁶⁶ A. Firan,⁴² A. Fischer,² C. Fischer,¹³ J. Fischer,¹⁷⁴ W. C. Fisher,⁹¹ N. Flaschel,⁴⁴ I. Fleck,¹⁴¹ P. Fleischmann,⁹⁰ G. T. Fletcher,¹³⁹ R. R. M. Fletcher,¹²² T. Flick,¹⁷⁴
- A. Floderus,⁸² L. R. Flores Castillo,^{61a} M. J. Flowerdew,¹⁰¹ G. T. Forcolin,⁸⁵ A. Formica,¹³⁶ A. Forti,⁸⁵ A. G. Foster,¹⁹ D. Fournier,¹¹⁷ H. Fox,⁷³ S. Fracchia,¹³ P. Francavilla,⁸¹ M. Franchini,^{22a,22b} D. Francis,³² L. Franconi,¹¹⁹ M. Franklin,⁵⁸
- M. Frate,¹⁶² M. Fraternali,^{121a,121b} D. Freeborn,⁷⁹ S. M. Fressard-Batraneanu,³² F. Friedrich,⁴⁶ D. Froidevaux,³² J. A. Frost,¹²⁰ C. Fukunaga,¹⁵⁶ E. Fullana Torregrosa,⁸⁴ T. Fusayasu,¹⁰² J. Fuster,¹⁶⁶ C. Gabaldon,⁵⁷ O. Gabizon,¹⁷⁴
- A. Gabrielli,^{22a,22b} A. Gabrielli,¹⁶ G. P. Gach,^{40a} S. Gadatsch,³² S. Gadomski,⁵¹ G. Gagliardi,^{52a,52b} L. G. Gagnon,⁹⁵ P. Gagnon,⁶² C. Galea,¹⁰⁶ B. Galhardo,^{126a,126c} E. J. Gallas,¹²⁰ B. J. Gallop,¹³¹ P. Gallus,¹²⁸ G. Galster,³⁸ K. K. Gan,¹¹¹
- J. Gao,^{35b,86} Y. Gao,⁴⁸ Y. S. Gao,^{143,g} F. M. Garay Walls,⁴⁸ C. García,¹⁶⁶ J. E. García Navarro,¹⁶⁶ M. Garcia-Sciveres,¹⁶ R. W. Gardner,³³ N. Garelli,¹⁴³ V. Garonne,¹¹⁹ A. Gascon Bravo,⁴⁴ K. Gasnikova,⁴⁴ C. Gatti,⁴⁹ A. Gaudiello,^{52a,52b}
- G. Gaudio,^{121a} L. Gauthier,⁹⁵ I. L. Gavrilenko,⁹⁶ C. Gay,¹⁶⁷ G. Gaycken,²³ E. N. Gazis,¹⁰ Z. Gecse,¹⁶⁷ C. N. P. Gee,¹³¹ Ch. Geich-Gimbel,²³ M. Geisen,⁸⁴ M. P. Geisler,^{59a} C. Gemme,^{52a} M. H. Genest,⁵⁷ C. Geng,^{35b,p} S. Gentile,^{132a,132b}
- C. Gentsos,¹⁵⁴ S. George,⁷⁸ D. Gerbaudo,¹³ A. Gershon,¹⁵³ S. Ghasemi,¹⁴¹ H. Ghazlane,^{135b} M. Ghneimat,²³ B. Giacobbe,^{22a} S. Giagu,^{132a,132b} P. Giannetti,^{124a,124b} B. Gibbard,²⁷ S. M. Gibson,⁷⁸ M. Gignac,¹⁶⁷ M. Gilchriese,¹⁶ T. P. S. Gillam,³⁰
- D. Gillberg,³¹ G. Gilles,¹⁷⁴ D. M. Gingrich,^{3,e} N. Giokaris,⁹ M. P. Giordani,^{163a,163c} F. M. Giorgi,^{22a} F. M. Giorgi,¹⁷ P. F. Giraud,¹³⁶ P. Giromini,⁵⁸ D. Giugni,^{92a} F. Giuli,¹²⁰ C. Giuliani,¹⁰¹ M. Giulini,^{59b} B. K. Gjeltsten,¹¹⁹ S. Gkaitatzis,¹⁵⁴
- I. Gkialas,¹⁵⁴ E. L. Gkougkousis,¹¹⁷ L. K. Gladilin,⁹⁹ C. Glasman,⁸³ J. Glatzer,⁵⁰ P. C. F. Glaysheer,⁴⁸ A. Glazov,⁴⁴

- M. Goblirsch-Kolb,²⁵ J. Godlewski,⁴¹ S. Goldfarb,⁸⁹ T. Golling,⁵¹ D. Golubkov,¹³⁰ A. Gomes,^{126a,126b,126d} R. Gonçalves,^{126a} J. Goncalves Pinto Firmino Da Costa,¹³⁶ G. Gonella,⁵⁰ L. Gonella,¹⁹ A. Gongadze,⁶⁶ S. González de la Hoz,¹⁶⁶ G. Gonzalez Parra,¹³ S. Gonzalez-Sevilla,⁵¹ L. Goossens,³² P. A. Gorbounov,⁹⁷ H. A. Gordon,²⁷ I. Gorelov,¹⁰⁵ B. Gorini,³² E. Gorini,^{74a,74b} A. Gorišek,⁷⁶ E. Gornicki,⁴¹ A. T. Goshaw,⁴⁷ C. Gössling,⁴⁵ M. I. Gostkin,⁶⁶ C. R. Goudet,¹¹⁷ D. Goujdami,^{135c} A. G. Goussiou,¹³⁸ N. Govender,^{145b,q} E. Gozani,¹⁵² L. Graber,⁵⁶ I. Grabowska-Bold,^{40a} P. O. J. Gradin,⁵⁷ P. Grafström,^{22a,22b} J. Gramling,⁵¹ E. Gramstad,¹¹⁹ S. Grancagnolo,¹⁷ V. Gratchev,¹²³ P. M. Gravila,^{28e} H. M. Gray,³² E. Graziani,^{134a} Z. D. Greenwood,^{80,r} C. Greife,²³ K. Gregersen,⁷⁹ I. M. Gregor,⁴⁴ P. Grenier,¹⁴³ K. Grevtsov,⁵ J. Griffiths,⁸ A. A. Grillo,¹³⁷ K. Grimm,⁷³ S. Grinstein,^{13,s} Ph. Gris,³⁶ J.-F. Grivaz,¹¹⁷ S. Groh,⁸⁴ J. P. Grohs,⁴⁶ E. Gross,¹⁷¹ J. Grosse-Knetter,⁵⁶ G. C. Grossi,⁸⁰ Z. J. Grout,⁷⁹ L. Guan,⁹⁰ W. Guan,¹⁷² J. Guenther,⁶³ F. Guescini,⁵¹ D. Guest,¹⁶² O. Gueta,¹⁵³ E. Guido,^{52a,52b} T. Guillemin,⁵ S. Guindon,² U. Gul,⁵⁵ C. Gumpert,³² J. Guo,^{35e} Y. Guo,^{35b,p} R. Gupta,⁴² S. Gupta,¹²⁰ G. Gustavino,^{132a,132b} P. Gutierrez,¹¹³ N. G. Gutierrez Ortiz,⁷⁹ C. Gutsche,⁴⁶ C. Guyot,¹³⁶ C. Gwenlan,¹²⁰ C. B. Gwilliam,⁷⁵ A. Haas,¹¹⁰ C. Haber,¹⁶ H. K. Hadavand,⁸ N. Haddad,^{135e} A. Hadeef,⁸⁶ S. Hageböck,²³ Z. Hajduk,⁴¹ H. Hakobyan,^{176,a} M. Haleem,⁴⁴ J. Haley,¹¹⁴ G. Halladjian,⁹¹ G. D. Hallewell,⁸⁶ K. Hamacher,¹⁷⁴ P. Hamal,¹¹⁵ K. Hamano,¹⁶⁸ A. Hamilton,^{145a} G. N. Hamity,¹³⁹ P. G. Hamnett,⁴⁴ L. Han,^{35b} K. Hanagaki,^{67,t} K. Hanawa,¹⁵⁵ M. Hance,¹³⁷ B. Haney,¹²² S. Hanisch,³² P. Hanke,^{59a} R. Hanna,¹³⁶ J. B. Hansen,³⁸ J. D. Hansen,³⁸ M. C. Hansen,²³ P. H. Hansen,³⁸ K. Hara,¹⁶⁰ A. S. Hard,¹⁷² T. Harenberg,¹⁷⁴ F. Hariri,¹¹⁷ S. Harkusha,⁹³ R. D. Harrington,⁴⁸ P. F. Harrison,¹⁶⁹ F. Hartjes,¹⁰⁷ N. M. Hartmann,¹⁰⁰ M. Hasegawa,⁶⁸ Y. Hasegawa,¹⁴⁰ A. Hasib,¹¹³ S. Hassani,¹³⁶ S. Haug,¹⁸ R. Hauser,⁹¹ L. Hauswald,⁴⁶ M. Havranek,¹²⁷ C. M. Hawkes,¹⁹ R. J. Hawkings,³² D. Hayakawa,¹⁵⁷ D. Hayden,⁹¹ C. P. Hays,¹²⁰ J. M. Hays,⁷⁷ H. S. Hayward,⁷⁵ S. J. Haywood,¹³¹ S. J. Head,¹⁹ T. Heck,⁸⁴ V. Hedberg,⁸² L. Heelan,⁸ S. Heim,¹²² T. Heim,¹⁶ B. Heinemann,¹⁶ J. J. Heinrich,¹⁰⁰ L. Heinrich,¹¹⁰ C. Heinz,⁵⁴ J. Hejbal,¹²⁷ L. Helary,³² S. Hellman,^{146a,146b} C. Helsen,³² J. Henderson,¹²⁰ R. C. W. Henderson,⁷³ Y. Heng,¹⁷² S. Henkelmann,¹⁶⁷ A. M. Henriques Correia,³² S. Henrot-Versille,¹¹⁷ G. H. Herbert,¹⁷ V. Herget,¹⁷³ Y. Hernández Jiménez,¹⁶⁶ G. Herten,⁵⁰ R. Hertenberger,¹⁰⁰ L. Hervas,³² G. G. Hesketh,⁷⁹ N. P. Hessey,¹⁰⁷ J. W. Hetherly,⁴² R. Hickling,⁷⁷ E. Higón-Rodríguez,¹⁶⁶ E. Hill,¹⁶⁸ J. C. Hill,³⁰ K. H. Hiller,⁴⁴ S. J. Hillier,¹⁹ I. Hinchliffe,¹⁶ E. Hines,¹²² R. R. Hinman,¹⁶ M. Hirose,⁵⁰ D. Hirschbuehl,¹⁷⁴ J. Hobbs,¹⁴⁸ N. Hod,^{159a} M. C. Hodgkinson,¹³⁹ P. Hodgson,¹³⁹ A. Hoecker,³² M. R. Hoefkamp,¹⁰⁵ F. Hoenig,¹⁰⁰ D. Hohn,²³ T. R. Holmes,¹⁶ M. Homann,⁴⁵ T. M. Hong,¹²⁵ B. H. Hooberman,¹⁶⁵ W. H. Hopkins,¹¹⁶ Y. Horii,¹⁰³ A. J. Horton,¹⁴² J.-Y. Hostachy,⁵⁷ S. Hou,¹⁵¹ A. Hoummada,^{135a} J. Howarth,⁴⁴ M. Hrabovsky,¹¹⁵ I. Hristova,¹⁷ J. Hrivnac,¹¹⁷ T. Hryn'ova,⁵ A. Hrynevich,⁹⁴ C. Hsu,^{145c} P. J. Hsu,^{151,u} S.-C. Hsu,¹³⁸ D. Hu,³⁷ Q. Hu,^{35b} S. Hu,^{35e} Y. Huang,⁴⁴ Z. Hubacek,¹²⁸ F. Hubaut,⁸⁶ F. Huegging,²³ T. B. Huffman,¹²⁰ E. W. Hughes,³⁷ G. Hughes,⁷³ M. Huhtinen,³² P. Huo,¹⁴⁸ N. Huseynov,^{66,c} J. Huston,⁹¹ J. Huth,⁵⁸ G. Iacobucci,⁵¹ G. Iakovidis,²⁷ I. Ibragimov,¹⁴¹ L. Iconomidou-Fayard,¹¹⁷ E. Ideal,¹⁷⁵ Z. Idrissi,^{135e} P. Iengo,³² O. Igonkina,^{107,v} T. Iizawa,¹⁷⁰ Y. Ikegami,⁶⁷ M. Ikeno,⁶⁷ Y. Ilchenko,^{11,w} D. Iliadis,¹⁵⁴ N. Ilic,¹⁴³ T. Ince,¹⁰¹ G. Introzzi,^{121a,121b} P. Ioannou,^{9,a} M. Iodice,^{134a} K. Iordanidou,³⁷ V. Ippolito,⁵⁸ N. Ishijima,¹¹⁸ M. Ishino,¹⁵⁵ M. Ishitsuka,¹⁵⁷ R. Ishmukhametov,¹¹¹ C. Issever,¹²⁰ S. Istin,^{20a} F. Ito,¹⁶⁰ J. M. Iturbe Ponce,⁸⁵ R. Iuppa,^{133a,133b} W. Iwanski,⁴¹ H. Iwasaki,⁶⁷ J. M. Izen,⁴³ V. Izzo,^{104a} S. Jabbar,³ B. Jackson,¹²² P. Jackson,¹ V. Jain,² K. B. Jakobi,⁸⁴ K. Jakobs,⁵⁰ S. Jakobsen,³² T. Jakoubek,¹²⁷ D. O. Jamin,¹¹⁴ D. K. Jana,⁸⁰ E. Jansen,⁷⁹ R. Jansky,⁶³ J. Janssen,²³ M. Janus,⁵⁶ G. Jarlskog,⁸² N. Javadov,^{66,c} T. Javůrek,⁵⁰ F. Jeanneau,¹³⁶ L. Jeanty,¹⁶ J. Jejelava,^{53a,x} G.-Y. Jeng,¹⁵⁰ D. Jennens,⁸⁹ P. Jenni,^{50,y} C. Jeske,¹⁶⁹ S. Jézéquel,⁵ H. Ji,¹⁷² J. Jia,¹⁴⁸ H. Jiang,⁶⁵ Y. Jiang,^{35b} S. Jiggins,⁷⁹ J. Jimenez Pena,¹⁶⁶ S. Jin,^{35a} A. Jinaru,^{28b} O. Jinnouchi,¹⁵⁷ H. Jivan,^{145c} P. Johansson,¹³⁹ K. A. Johns,⁷ W. J. Johnson,¹³⁸ K. Jon-And,^{146a,146b} G. Jones,¹⁶⁹ R. W. L. Jones,⁷³ S. Jones,⁷ T. J. Jones,⁷⁵ J. Jongmanns,^{59a} P. M. Jorge,^{126a,126b} J. Jovicevic,^{159a} X. Ju,¹⁷² A. Juste Rozas,^{13,s} M. K. Köhler,¹⁷¹ A. Kaczmarek,⁴¹ M. Kado,¹¹⁷ H. Kagan,¹¹¹ M. Kagan,¹⁴³ S. J. Kahn,⁸⁶ T. Kaji,¹⁷⁰ E. Kajomovitz,⁴⁷ C. W. Kalderon,¹²⁰ A. Kaluza,⁸⁴ S. Kama,⁴² A. Kamenshchikov,¹³⁰ N. Kanaya,¹⁵⁵ S. Kaneti,³⁰ L. Kanjir,⁷⁶ V. A. Kantserov,⁹⁸ J. Kanzaki,⁶⁷ B. Kaplan,¹¹⁰ L. S. Kaplan,¹⁷² A. Kapliy,³³ D. Kar,^{145c} K. Karakostas,¹⁰ A. Karamaoun,³ N. Karastathis,¹⁰ M. J. Kareem,⁵⁶ E. Karentzos,¹⁰ M. Karnevskiy,⁸⁴ S. N. Karpov,⁶⁶ Z. M. Karpova,⁶⁶ K. Karthik,¹¹⁰ V. Kartvelishvili,⁷³ A. N. Karyukhin,¹³⁰ K. Kasahara,¹⁶⁰ L. Kashif,¹⁷² R. D. Kass,¹¹¹ A. Kastanas,¹⁵ Y. Kataoka,¹⁵⁵ C. Kato,¹⁵⁵ A. Katre,⁵¹ J. Katzy,⁴⁴ K. Kawagoe,⁷¹ T. Kawamoto,¹⁵⁵ G. Kawamura,⁵⁶ V. F. Kazanin,^{109,d} R. Keeler,¹⁶⁸ R. Kehoe,⁴² J. S. Keller,⁴⁴ J. J. Kempster,⁷⁸ K. Kentaro,¹⁰³ H. Keoshkerian,¹⁵⁸ O. Kepka,¹²⁷ B. P. Kerševan,⁷⁶ S. Kersten,¹⁷⁴ R. A. Keyes,⁸⁸ M. Khader,¹⁶⁵ F. Khalil-zada,¹² A. Khanov,¹¹⁴ A. G. Kharlamov,^{109,d} T. J. Khoo,⁵¹ V. Khovanskiy,⁹⁷ E. Khramov,⁶⁶ J. Khubua,^{53b,z} S. Kido,⁶⁸ C. R. Kilby,⁷⁸ H. Y. Kim,⁸ S. H. Kim,¹⁶⁰ Y. K. Kim,³³ N. Kimura,¹⁵⁴ O. M. Kind,¹⁷ B. T. King,⁷⁵ M. King,¹⁶⁶ S. B. King,¹⁶⁷ J. Kirk,¹³¹ A. E. Kiryunin,¹⁰¹ T. Kishimoto,¹⁵⁵ D. Kisieleska,^{40a} F. Kiss,⁵⁰ K. Kiuchi,¹⁶⁰ O. Kivernyk,¹³⁶ E. Kladiva,^{144b} M. H. Klein,³⁷

- M. Klein,⁷⁵ U. Klein,⁷⁵ K. Kleinknecht,⁸⁴ P. Klimek,¹⁰⁸ A. Klimentov,²⁷ R. Klingenberg,⁴⁵ J. A. Klinger,¹³⁹
T. Klioutchnikova,³² E.-E. Kluge,^{59a} P. Kluit,¹⁰⁷ S. Kluth,¹⁰¹ J. Knapik,⁴¹ E. Kneringer,⁶³ E. B. F. G. Knoops,⁸⁶ A. Knue,⁵⁵
A. Kobayashi,¹⁵⁵ D. Kobayashi,¹⁵⁷ T. Kobayashi,¹⁵⁵ M. Kobel,⁴⁶ M. Kocian,¹⁴³ P. Kodys,¹²⁹ N. M. Koehler,¹⁰¹ T. Koffas,³¹
E. Koffeman,¹⁰⁷ T. Koi,¹⁴³ H. Kolanoski,¹⁷ M. Kolb,^{59b} I. Koletsou,⁵ A. A. Komar,^{96a} Y. Komori,¹⁵⁵ T. Kondo,⁶⁷
N. Kondrashova,⁴⁴ K. Köneke,⁵⁰ A. C. König,¹⁰⁶ T. Kono,^{67aa} R. Konoplich,^{110bb} N. Konstantinidis,⁷⁹ R. Kopeliansky,⁶²
S. Koperny,^{40a} L. Köpke,⁸⁴ A. K. Kopp,⁵⁰ K. Korcyl,⁴¹ K. Kordas,¹⁵⁴ A. Korn,⁷⁹ A. A. Korol,^{109d} I. Korolkov,¹³
E. V. Korolkova,¹³⁹ O. Kortner,¹⁰¹ S. Kortner,¹⁰¹ T. Kosek,¹²⁹ V. V. Kostyukhin,²³ A. Kotwal,⁴⁷
A. Kourkouveli-Charalampidi,^{121a,121b} C. Kourkouvelis,⁹ V. Kouskoura,²⁷ A. B. Kowalewska,⁴¹ R. Kowalewski,¹⁶⁸
T. Z. Kowalski,^{40a} C. Kozakai,¹⁵⁵ W. Kozanecki,¹³⁶ A. S. Kozhin,¹³⁰ V. A. Kramarenko,⁹⁹ G. Kramberger,⁷⁶
D. Krasnopevtsev,⁹⁸ M. W. Krasny,⁸¹ A. Krasznahorkay,³² A. Kravchenko,²⁷ M. Kretz,^{59c} J. Kretzschmar,⁷⁵
K. Kreutzfeldt,⁵⁴ P. Krieger,¹⁵⁸ K. Krizka,³³ K. Kroeninger,⁴⁵ H. Kroha,¹⁰¹ J. Kroll,¹²² J. Kroseberg,²³ J. Krstic,¹⁴
U. Kruchonak,⁶⁶ H. Krüger,²³ N. Krumnack,⁶⁵ A. Kruse,¹⁷² M. C. Kruse,⁴⁷ M. Kruskal,²⁴ T. Kubota,⁸⁹ H. Kucuk,⁷⁹
S. Kuday,^{4b} J. T. Kuechler,¹⁷⁴ S. Kuehn,⁵⁰ A. Kugel,^{59c} F. Kuger,¹⁷³ A. Kuhl,¹³⁷ T. Kuhl,⁴⁴ V. Kukhtin,⁶⁶ R. Kukla,¹³⁶
Y. Kulchitsky,⁹³ S. Kuleshov,^{34b} M. Kuna,^{132a,132b} T. Kunigo,⁶⁹ A. Kupco,¹²⁷ H. Kurashige,⁶⁸ Y. A. Kurochkin,⁹³ V. Kus,¹²⁷
E. S. Kuwertz,¹⁶⁸ M. Kuze,¹⁵⁷ J. Kvita,¹¹⁵ T. Kwan,¹⁶⁸ D. Kyriazopoulos,¹³⁹ A. La Rosa,¹⁰¹ J. L. La Rosa Navarro,^{26d}
L. La Rotonda,^{39a,39b} C. Lacasta,¹⁶⁶ F. Lacava,^{132a,132b} J. Lacey,³¹ H. Lacker,¹⁷ D. Lacour,⁸¹ V. R. Lacuesta,¹⁶⁶ E. Ladygin,⁶⁶
R. Lafaye,⁵ B. Laforge,⁸¹ T. Lagouri,¹⁷⁵ S. Lai,⁵⁶ S. Lammers,⁶² W. Lampl,⁷ E. Lançon,¹³⁶ U. Landgraf,⁵⁰ M. P. J. Landon,⁷⁷
M. C. Lanfermann,⁵¹ V. S. Lang,^{59a} J. C. Lange,¹³ A. J. Lankford,¹⁶² F. Lanni,²⁷ K. Lantzsch,²³ A. Lanza,^{121a} S. Laplace,⁸¹
C. Lapoire,³² J. F. Laporte,¹³⁶ T. Lari,^{92a} F. Lasagni Manghi,^{22a,22b} M. Lassnig,³² P. Laurelli,⁴⁹ W. Lavrijsen,¹⁶ A. T. Law,¹³⁷
P. Laycock,⁷⁵ T. Lazovich,⁵⁸ M. Lazzaroni,^{92a,92b} B. Le,⁸⁹ O. Le Dortz,⁸¹ E. Le Guirriec,⁸⁶ E. P. Le Quilleuc,¹³⁶
M. LeBlanc,¹⁶⁸ T. LeCompte,⁶ F. Ledroit-Guillon,⁵⁷ C. A. Lee,²⁷ S. C. Lee,¹⁵¹ L. Lee,¹ B. Lefebvre,⁸⁸ G. Lefebvre,⁸¹
M. Lefebvre,¹⁶⁸ F. Legger,¹⁰⁰ C. Leggett,¹⁶ A. Lehan,⁷⁵ G. Lehmann Miotto,³² X. Lei,⁷ W. A. Leight,³¹ A. Leisos,^{154cc}
A. G. Leister,¹⁷⁵ M. A. L. Leite,^{26d} R. Leitner,¹²⁹ D. Lellouch,¹⁷¹ B. Lemmer,⁵⁶ K. J. C. Leney,⁷⁹ T. Lenz,²³ B. Lenzi,³²
R. Leone,⁷ S. Leone,^{124a,124b} C. Leonidopoulos,⁴⁸ S. Leontsinis,¹⁰ G. Lerner,¹⁴⁹ C. Leroy,⁹⁵ A. A. J. Lesage,¹³⁶ C. G. Lester,³⁰
M. Levchenko,¹²³ J. Levêque,⁵ D. Levin,⁹⁰ L. J. Levinson,¹⁷¹ M. Levy,¹⁹ D. Lewis,⁷⁷ A. M. Leyko,²³ M. Leyton,⁴³ B. Li,^{35b,p}
C. Li,^{35b} H. Li,¹⁴⁸ H. L. Li,³³ L. Li,⁴⁷ L. Li,^{35e} Q. Li,^{35a} S. Li,⁴⁷ X. Li,⁸⁵ Y. Li,¹⁴¹ Z. Liang,^{35a} B. Liberti,^{133a} A. Liblong,¹⁵⁸
P. Lichard,³² K. Lie,¹⁶⁵ J. Liebal,²³ W. Liebig,¹⁵ A. Limosani,¹⁵⁰ S. C. Lin,^{151dd} T. H. Lin,⁸⁴ B. E. Lindquist,¹⁴⁸ A. E. Lioni,⁵¹
E. Lipeles,¹²² A. Lipniacka,¹⁵ M. Lisovyi,^{59b} T. M. Liss,¹⁶⁵ A. Lister,¹⁶⁷ A. M. Litke,¹³⁷ B. Liu,^{151ee} D. Liu,¹⁵¹ H. Liu,⁹⁰
H. Liu,²⁷ J. Liu,⁸⁶ J. B. Liu,^{35b} K. Liu,⁸⁶ L. Liu,¹⁶⁵ M. Liu,⁴⁷ M. Liu,^{35b} Y. L. Liu,^{35b} Y. Liu,^{35b} M. Livan,^{121a,121b} A. Lleres,⁵⁷
J. Llorente Merino,^{35a} S. L. Lloyd,⁷⁷ F. Lo Sterzo,¹⁵¹ E. Lobodzinska,⁴⁴ P. Loch,⁷ W. S. Lockman,¹³⁷ F. K. Loebinger,⁸⁵
A. E. Loevschall-Jensen,³⁸ K. M. Loew,²⁵ A. Loginov,^{175a} T. Lohse,¹⁷ K. Lohwasser,⁴⁴ M. Lokajicek,¹²⁷ B. A. Long,²⁴
J. D. Long,¹⁶⁵ R. E. Long,⁷³ L. Longo,^{74a,74b} K. A. Looper,¹¹¹ L. Lopes,^{126a} D. Lopez Mateos,⁵⁸ B. Lopez Paredes,¹³⁹
I. Lopez Paz,¹³ A. Lopez Solis,⁸¹ J. Lorenz,¹⁰⁰ N. Lorenzo Martinez,⁶² M. Losada,²¹ P. J. Lösel,¹⁰⁰ X. Lou,^{35a} A. Lounis,¹¹⁷
J. Love,⁶ P. A. Love,⁷³ H. Lu,^{61a} N. Lu,⁹⁰ H. J. Lubatti,¹³⁸ C. Luci,^{132a,132b} A. Lucotte,⁵⁷ C. Luedtke,⁵⁰ F. Luehring,⁶²
W. Lukas,⁶³ L. Luminari,^{132a} O. Lundberg,^{146a,146b} B. Lund-Jensen,¹⁴⁷ P. M. Luzi,⁸¹ D. Lynn,²⁷ R. Lysak,¹²⁷ E. Lytken,⁸²
V. Lyubushkin,⁶⁶ H. Ma,²⁷ L. L. Ma,^{35d} Y. Ma,^{35d} G. Maccarrone,⁴⁹ A. Macchiolo,¹⁰¹ C. M. Macdonald,¹³⁹ B. Maček,⁷⁶
J. Machado Miguens,^{122,126b} D. Madaffari,⁸⁶ R. Madar,³⁶ H. J. Maddocks,¹⁶⁴ W. F. Mader,⁴⁶ A. Madsen,⁴⁴ J. Maeda,⁶⁸
S. Maeland,¹⁵ T. Maeno,²⁷ A. Maevskiy,⁹⁹ E. Magradze,⁵⁶ J. Mahlstedt,¹⁰⁷ C. Maiani,¹¹⁷ C. Maidantchik,^{26a} A. A. Maier,¹⁰¹
T. Maier,¹⁰⁰ A. Maio,^{126a,126b,126d} S. Majewski,¹¹⁶ Y. Makida,⁶⁷ N. Makovec,¹¹⁷ B. Malaescu,⁸¹ Pa. Malecki,⁴¹
V. P. Maleev,¹²³ F. Malek,⁵⁷ U. Mallik,⁶⁴ D. Malon,⁶ C. Malone,¹⁴³ S. Maltezos,¹⁰ S. Malyukov,³² J. Mamuzic,¹⁶⁶
G. Mancini,⁴⁹ B. Mandelli,³² L. Mandelli,^{92a} I. Mandić,⁷⁶ J. Maneira,^{126a,126b} L. Manhaes de Andrade Filho,^{26b}
J. Manjarres Ramos,^{159b} A. Mann,¹⁰⁰ A. Manousos,³² B. Mansoulie,¹³⁶ J. D. Mansour,^{35a} R. Mantifel,⁸⁸ M. Mantoani,⁵⁶
S. Manzoni,^{92a,92b} L. Mapelli,³² G. Marceca,²⁹ L. March,⁵¹ G. Marchiori,⁸¹ M. Marcisovsky,¹²⁷ M. Marjanovic,¹⁴
D. E. Marley,⁹⁰ F. Marroquim,^{26a} S. P. Marsden,⁸⁵ Z. Marshall,¹⁶ S. Marti-Garcia,¹⁶⁶ B. Martin,⁹¹ T. A. Martin,¹⁶⁹
V. J. Martin,⁴⁸ B. Martin dit Latour,¹⁵ M. Martinez,^{13s} V. I. Martinez Outschoorn,¹⁶⁵ S. Martin-Haugh,¹³¹ V. S. Martoiu,^{28b}
A. C. Martyniuk,⁷⁹ M. Marx,¹³⁸ A. Marzin,³² L. Masetti,⁸⁴ T. Mashimo,¹⁵⁵ R. Mashinistov,⁹⁶ J. Masik,⁸⁵
A. L. Maslennikov,^{109d} I. Massa,^{22a,22b} L. Massa,^{22a,22b} P. Mastrandrea,⁵ A. Mastroberardino,^{39a,39b} T. Masubuchi,¹⁵⁵
P. Mättig,¹⁷⁴ J. Mattmann,⁸⁴ J. Maurer,^{28b} S. J. Maxfield,⁷⁵ D. A. Maximov,^{109d} R. Mazini,¹⁵¹ S. M. Mazza,^{92a,92b}
N. C. Mc Fadden,¹⁰⁵ G. Mc Goldrick,¹⁵⁸ S. P. Mc Kee,⁹⁰ A. McCarn,⁹⁰ R. L. McCarthy,¹⁴⁸ T. G. McCarthy,¹⁰¹

- L. I. McClymont,⁷⁹ E. F. McDonald,⁸⁹ J. A. Mcfayden,⁷⁹ G. Mchedlidze,⁵⁶ S. J. McMahon,¹³¹ R. A. McPherson,^{168,m} M. Medinnis,⁴⁴ S. Meehan,¹³⁸ S. Mehlhase,¹⁰⁰ A. Mehta,⁷⁵ K. Meier,^{59a} C. Meineck,¹⁰⁰ B. Meirose,⁴³ D. Melini,¹⁶⁶ B. R. Mellado Garcia,^{145c} M. Melo,^{144a} F. Meloni,¹⁸ A. Mengarelli,^{22a,22b} S. Menke,¹⁰¹ E. Meoni,¹⁶¹ S. Mergelmeyer,¹⁷ P. Mermoud,⁵¹ L. Merola,^{104a,104b} C. Meroni,^{92a} F. S. Merritt,³³ A. Messina,^{132a,132b} J. Metcalfe,⁶ A. S. Mete,¹⁶² C. Meyer,⁸⁴ C. Meyer,¹²² J.-P. Meyer,¹³⁶ J. Meyer,¹⁰⁷ H. Meyer Zu Theenhausen,^{59a} F. Miano,¹⁴⁹ R. P. Middleton,¹³¹ S. Miglioranza,^{52a,52b} L. Mijović,⁴⁸ G. Mikenberg,¹⁷¹ M. Mikestikova,¹²⁷ M. Mikuž,⁷⁶ M. Milesi,⁸⁹ A. Milic,⁶³ D. W. Miller,³³ C. Mills,⁴⁸ A. Milov,¹⁷¹ D. A. Milstead,^{146a,146b} A. A. Minaenko,¹³⁰ Y. Minami,¹⁵⁵ I. A. Minashvili,⁶⁶ A. I. Mincer,¹¹⁰ B. Mindur,^{40a} M. Mineev,⁶⁶ Y. Ming,¹⁷² L. M. Mir,¹³ K. P. Mistry,¹²² T. Mitani,¹⁷⁰ J. Mitrevski,¹⁰⁰ V. A. Mitsou,¹⁶⁶ A. Miucci,⁵¹ P. S. Miyagawa,¹³⁹ J. U. Mjörnmark,⁸² T. Moa,^{146a,146b} K. Mochizuki,⁹⁵ S. Mohapatra,³⁷ S. Molander,^{146a,146b} R. Moles-Valls,²³ R. Monden,⁶⁹ M. C. Mondragon,⁹¹ K. Mönig,⁴⁴ J. Monk,³⁸ E. Monnier,⁸⁶ A. Montalbano,¹⁴⁸ J. Montejo Berlingen,³² F. Monticelli,⁷² S. Monzani,^{92a,92b} R. W. Moore,³ N. Morange,¹¹⁷ D. Moreno,²¹ M. Moreno Llácer,⁵⁶ P. Moretini,^{52a} D. Mori,¹⁴² T. Mori,¹⁵⁵ M. Morii,⁵⁸ M. Morinaga,¹⁵⁵ V. Morisbak,¹¹⁹ S. Moritz,⁸⁴ A. K. Morley,¹⁵⁰ G. Mornacchi,³² J. D. Morris,⁷⁷ S. S. Mortensen,³⁸ L. Morvaj,¹⁴⁸ M. Mosidze,^{53b} J. Moss,¹⁴³ K. Motohashi,¹⁵⁷ R. Mount,¹⁴³ E. Mountricha,²⁷ S. V. Mouraviev,^{96a} E. J. W. Moyse,⁸⁷ S. Muanza,⁸⁶ R. D. Mudd,¹⁹ F. Mueller,¹⁰¹ J. Mueller,¹²⁵ R. S. P. Mueller,¹⁰⁰ T. Mueller,³⁰ D. Muenstermann,⁷³ P. Mullen,⁵⁵ G. A. Mullier,¹⁸ F. J. Munoz Sanchez,⁸⁵ J. A. Murillo Quijada,¹⁹ W. J. Murray,^{169,131} H. Musheghyan,⁵⁶ M. Muškinja,⁷⁶ A. G. Myagkov,^{130,ff} M. Myska,¹²⁸ B. P. Nachman,¹⁴³ O. Nackenhorst,⁵¹ K. Nagai,¹²⁰ R. Nagai,^{67,aa} K. Nagano,⁶⁷ Y. Nagasaka,⁶⁰ K. Nagata,¹⁶⁰ M. Nagel,⁵⁰ E. Nagy,⁸⁶ A. M. Nairz,³² Y. Nakahama,¹⁰³ K. Nakamura,⁶⁷ T. Nakamura,¹⁵⁵ I. Nakano,¹¹² H. Namasivayam,⁴³ R. F. Naranjo Garcia,⁴⁴ R. Narayan,¹¹ D. I. Narrias Villar,^{59a} I. Naryshkin,¹²³ T. Naumann,⁴⁴ G. Navarro,²¹ R. Nayyar,⁷ H. A. Neal,⁹⁰ P. Yu. Nechaeva,⁹⁶ T. J. Neep,⁸⁵ A. Negri,^{121a,121b} M. Negrini,^{22a} S. Nektarijevic,¹⁰⁶ C. Nellist,¹¹⁷ A. Nelson,¹⁶² S. Nemecek,¹²⁷ P. Nemethy,¹¹⁰ A. A. Nepomuceno,^{26a} M. Nessi,^{32,gg} M. S. Neubauer,¹⁶⁵ M. Neumann,¹⁷⁴ R. M. Neves,¹¹⁰ P. Nevski,²⁷ P. R. Newman,¹⁹ D. H. Nguyen,⁶ T. Nguyen Manh,⁹⁵ R. B. Nickerson,¹²⁰ R. Nicolaidou,¹³⁶ J. Nielsen,¹³⁷ A. Nikiforov,¹⁷ V. Nikolaenko,^{130,ff} I. Nikolic-Audit,⁸¹ K. Nikolopoulos,¹⁹ J. K. Nilsen,¹¹⁹ P. Nilsson,²⁷ Y. Ninomiya,¹⁵⁵ A. Nisati,^{132a} R. Nisius,¹⁰¹ T. Nobe,¹⁵⁵ M. Nomachi,¹¹⁸ I. Nomidis,³¹ T. Nooney,⁷⁷ S. Norberg,¹¹³ M. Nordberg,³² N. Norjoharuddeen,¹²⁰ O. Novgorodova,⁴⁶ S. Nowak,¹⁰¹ M. Nozaki,⁶⁷ L. Nozka,¹¹⁵ K. Ntekas,¹⁰ E. Nurse,⁷⁹ F. Nuti,⁸⁹ F. O'grady,⁷ D. C. O'Neil,¹⁴² A. A. O'Rourke,⁴⁴ V. O'Shea,⁵⁵ F. G. Oakham,^{31,e} H. Oberlack,¹⁰¹ T. Obermann,²³ J. Ocariz,⁸¹ A. Ochi,⁶⁸ I. Ochoa,³⁷ J. P. Ochoa-Ricoux,^{34a} S. Oda,⁷¹ S. Odaka,⁶⁷ H. Ogren,⁶² A. Oh,⁸⁵ S. H. Oh,⁴⁷ C. C. Ohm,¹⁶ H. Ohman,¹⁶⁴ H. Oide,³² H. Okawa,¹⁶⁰ Y. Okumura,¹⁵⁵ T. Okuyama,⁶⁷ A. Olariu,^{28b} L. F. Oleiro Seabra,^{126a} S. A. Olivares Pino,⁴⁸ D. Oliveira Damazio,²⁷ A. Olszewski,⁴¹ J. Olszowska,⁴¹ A. Onofre,^{126a,126e} K. Onogi,¹⁰³ P. U. E. Onyisi,^{11,w} M. J. Oreglia,³³ Y. Oren,¹⁵³ D. Orestano,^{134a,134b} N. Orlando,^{61b} R. S. Orr,¹⁵⁸ B. Osculati,^{52a,52b} R. Ospanov,⁸⁵ G. Otero y Garzon,²⁹ H. Otono,⁷¹ M. Ouchrif,^{135d} F. Ould-Saada,¹¹⁹ A. Ouraou,¹³⁶ K. P. Oussoren,¹⁰⁷ Q. Ouyang,^{35a} M. Owen,⁵⁵ R. E. Owen,¹⁹ V. E. Ozcan,^{20a} N. Ozturk,⁸ K. Pachal,¹⁴² A. Pacheco Pages,¹³ L. Pacheco Rodriguez,¹³⁶ C. Padilla Aranda,¹³ M. Pagáčová,⁵⁰ S. Pagan Griso,¹⁶ F. Paige,²⁷ P. Pais,⁸⁷ K. Pajchel,¹¹⁹ G. Palacino,^{159b} S. Palazzo,^{39a,39b} S. Palestini,³² M. Palka,^{40b} D. Pallin,³⁶ E. St. Panagiotopoulou,¹⁰ C. E. Pandini,⁸¹ J. G. Panduro Vazquez,⁷⁸ P. Pani,^{146a,146b} S. Panitkin,²⁷ D. Pantea,^{28b} L. Paolozzi,⁵¹ Th. D. Papadopoulos,¹⁰ K. Papageorgiou,¹⁵⁴ A. Paramonov,⁶ D. Paredes Hernandez,¹⁷⁵ A. J. Parker,⁷³ M. A. Parker,³⁰ K. A. Parker,¹³⁹ F. Parodi,^{52a,52b} J. A. Parsons,³⁷ U. Parzefall,⁵⁰ V. R. Pascuzzi,¹⁵⁸ E. Pasqualucci,^{132a} S. Passaggio,^{52a} Fr. Pastore,⁷⁸ G. Pásztor,^{31,hh} S. Patariaia,¹⁷⁴ J. R. Pater,⁸⁵ T. Pauly,³² J. Pearce,¹⁶⁸ B. Pearson,¹¹³ L. E. Pedersen,³⁸ M. Pedersen,¹¹⁹ S. Pedraza Lopez,¹⁶⁶ R. Pedro,^{126a,126b} S. V. Peleganchuk,^{109,d} O. Penc,¹²⁷ C. Peng,^{35a} H. Peng,^{35b} J. Penwell,⁶² B. S. Peralva,^{26b} M. M. Perego,¹³⁶ D. V. Perepelitsa,²⁷ E. Perez Codina,^{159a} L. Perini,^{92a,92b} H. Pernegger,³² S. Perrella,^{104a,104b} R. Peschke,⁴⁴ V. D. Peshekhonov,⁶⁶ K. Peters,⁴⁴ R. F. Y. Peters,⁸⁵ B. A. Petersen,³² T. C. Petersen,³⁸ E. Petit,⁵⁷ A. Petridis,¹ C. Petridou,¹⁵⁴ P. Petroff,¹¹⁷ E. Petrolo,^{132a} M. Petrov,¹²⁰ F. Petrucci,^{134a,134b} N. E. Pettersson,⁸⁷ A. Peyaud,¹³⁶ R. Pezoa,^{34b} P. W. Phillips,¹³¹ G. Piacquadio,¹⁴³ E. Pianori,¹⁶⁹ A. Picazio,⁸⁷ E. Piccaro,⁷⁷ M. Piccinini,^{22a,22b} M. A. Pickering,¹²⁰ R. Piegaiia,²⁹ J. E. Pilcher,³³ A. D. Pilkington,⁸⁵ A. W. J. Pin,⁸⁵ M. Pinamonti,^{163a,163c,ii} J. L. Pinfold,³ A. Pingel,³⁸ S. Pires,⁸¹ H. Pirumov,⁴⁴ M. Pitt,¹⁷¹ L. Plazak,^{144a} M.-A. Pleier,²⁷ V. Pleskot,⁸⁴ E. Plotnikova,⁶⁶ P. Plucinski,⁹¹ D. Pluth,⁶⁵ R. Poettgen,^{146a,146b} L. Poggioli,¹¹⁷ D. Pohl,²³ G. Polesello,^{121a} A. Poley,⁴⁴ A. Policicchio,^{39a,39b} R. Polifka,¹⁵⁸ A. Polini,^{22a} C. S. Pollard,⁵⁵ V. Polychronakos,²⁷ K. Pommès,³² L. Pontecorvo,^{132a} B. G. Pope,⁹¹ G. A. Popeneciu,^{28c} A. Poppleton,³² S. Pospisil,¹²⁸ K. Potamianos,¹⁶ I. N. Potrap,⁶⁶ C. J. Potter,³⁰ C. T. Potter,¹¹⁶ G. Poulard,³² J. Poveda,³² V. Pozdnyakov,⁶⁶ M. E. Pozo Astigarraga,³² P. Pralavorio,⁸⁶ A. Pranko,¹⁶ S. Prell,⁶⁵ D. Price,⁸⁵ L. E. Price,⁶ M. Primavera,^{74a}

- S. Prince,⁸⁸ K. Prokofiev,^{61c} F. Prokoshin,^{34b} S. Protopopescu,²⁷ J. Proudfoot,⁶ M. Przybycien,^{40a} D. Puddu,^{134a,134b} M. Purohit,^{27,jj} P. Puzo,¹¹⁷ J. Qian,⁹⁰ G. Qin,⁵⁵ Y. Qin,⁸⁵ A. Quadt,⁵⁶ W. B. Quayle,^{163a,163b} M. Queitsch-Maitland,⁸⁵ D. Quilty,⁵⁵ S. Raddum,¹¹⁹ V. Radeka,²⁷ V. Radescu,¹²⁰ S. K. Radhakrishnan,¹⁴⁸ P. Radloff,¹¹⁶ P. Rados,⁸⁹ F. Ragusa,^{92a,92b} G. Rahal,¹⁷⁷ J. A. Raine,⁸⁵ S. Rajagopalan,²⁷ M. Rammensee,³² C. Rangel-Smith,¹⁶⁴ M. G. Ratti,^{92a,92b} F. Rauscher,¹⁰⁰ S. Rave,⁸⁴ T. Ravenscroft,⁵⁵ I. Ravinovich,¹⁷¹ M. Raymond,³² A. L. Read,¹¹⁹ N. P. Readioff,⁷⁵ M. Reale,^{74a,74b} D. M. Rebuffi,^{121a,121b} A. Redelbach,¹⁷³ G. Redlinger,²⁷ R. Reece,¹³⁷ K. Reeves,⁴³ L. Rehnisch,¹⁷ J. Reichert,¹²² H. Reisin,²⁹ C. Rembser,³² H. Ren,^{35a} M. Rescigno,^{132a} S. Resconi,^{92a} O. L. Rezanova,^{109,d} P. Reznicek,¹²⁹ R. Rezvani,⁹⁵ R. Richter,¹⁰¹ S. Richter,⁷⁹ E. Richter-Was,^{40b} O. Ricken,²³ M. Ridel,⁸¹ P. Rieck,¹⁷ C. J. Riegel,¹⁷⁴ J. Rieger,⁵⁶ O. Rifki,¹¹³ M. Rijssenbeek,¹⁴⁸ A. Rimoldi,^{121a,121b} M. Rimoldi,¹⁸ L. Rinaldi,^{22a} B. Ristić,⁵¹ E. Ritsch,³² I. Riu,¹³ F. Rizatdinova,¹¹⁴ E. Rizvi,⁷⁷ C. Rizzi,¹³ S. H. Robertson,^{88,m} A. Robichaud-Veronneau,⁸⁸ D. Robinson,³⁰ J. E. M. Robinson,⁴⁴ A. Robson,⁵⁵ C. Roda,^{124a,124b} Y. Rodina,⁸⁶ A. Rodriguez Perez,¹³ D. Rodriguez Rodriguez,¹⁶⁶ S. Roe,³² C. S. Rogan,⁵⁸ O. Røhne,¹¹⁹ A. Romanouk,⁹⁸ M. Romano,^{22a,22b} S. M. Romano Saez,³⁶ E. Romero Adam,¹⁶⁶ N. Rompotis,¹³⁸ M. Ronzani,⁵⁰ L. Roos,⁸¹ E. Ros,¹⁶⁶ S. Rosati,^{132a} K. Rosbach,⁵⁰ P. Rose,¹³⁷ O. Rosenthal,¹⁴¹ N.-A. Rosien,⁵⁶ V. Rossetti,^{146a,146b} E. Rossi,^{104a,104b} L. P. Rossi,^{52a} J. H. N. Rosten,³⁰ R. Rosten,¹³⁸ M. Rotaru,^{28b} I. Roth,¹⁷¹ J. Rothberg,¹³⁸ D. Rousseau,¹¹⁷ C. R. Royon,¹³⁶ A. Rozanov,⁸⁶ Y. Rozen,¹⁵² X. Ruan,^{145c} F. Rubbo,¹⁴³ M. S. Rudolph,¹⁵⁸ F. Rühr,⁵⁰ A. Ruiz-Martinez,³¹ Z. Rurikova,⁵⁰ N. A. Rusakovich,⁶⁶ A. Ruschke,¹⁰⁰ H. L. Russell,¹³⁸ J. P. Rutherford,⁷ N. Ruthmann,³² Y. F. Ryabov,¹²³ M. Rybar,¹⁶⁵ G. Rybkin,¹¹⁷ S. Ryu,⁶ A. Ryzhov,¹³⁰ G. F. Rzehorz,⁵⁶ A. F. Saavedra,¹⁵⁰ G. Sabato,¹⁰⁷ S. Sacerdoti,²⁹ H. F.-W. Sadrozinski,¹³⁷ R. Sadykov,⁶⁶ F. Safai Tehrani,^{132a} P. Saha,¹⁰⁸ M. Sahinsoy,^{59a} M. Saimpert,¹³⁶ T. Saito,¹⁵⁵ H. Sakamoto,¹⁵⁵ Y. Sakurai,¹⁷⁰ G. Salamanna,^{134a,134b} A. Salamon,^{133a,133b} J. E. Salazar Loyola,^{34b} D. Salek,¹⁰⁷ P. H. Sales De Bruin,¹³⁸ D. Salihagic,¹⁰¹ A. Salnikov,¹⁴³ J. Salt,¹⁶⁶ D. Salvatore,^{39a,39b} F. Salvatore,¹⁴⁹ A. Salvucci,^{61a} A. Salzburger,³² D. Sammel,⁵⁰ D. Sampsonidis,¹⁵⁴ A. Sanchez,^{104a,104b} J. Sánchez,¹⁶⁶ V. Sanchez Martinez,¹⁶⁶ H. Sandaker,¹¹⁹ R. L. Sandbach,⁷⁷ H. G. Sander,⁸⁴ M. Sandhoff,¹⁷⁴ C. Sandoval,²¹ R. Sandstroem,¹⁰¹ D. P. C. Sankey,¹³¹ M. Sannino,^{52a,52b} A. Sansoni,⁴⁹ C. Santoni,³⁶ R. Santonico,^{133a,133b} H. Santos,^{126a} I. Santoyo Castillo,¹⁴⁹ K. Sapp,¹²⁵ A. Saponov,⁶⁶ J. G. Saraiva,^{126a,126d} B. Sarrazin,²³ O. Sasaki,⁶⁷ Y. Sasaki,¹⁵⁵ K. Sato,¹⁶⁰ G. Sauvage,^{5,a} E. Sauvan,⁵ G. Savage,⁷⁸ P. Savard,^{158,e} N. Savic,¹⁰¹ C. Sawyer,¹³¹ L. Sawyer,^{80,r} J. Saxon,³³ C. Sbarra,^{22a} A. Sbrizzi,^{22a,22b} T. Scanlon,⁷⁹ D. A. Scannicchio,¹⁶² M. Scarcella,¹⁵⁰ V. Scarfone,^{39a,39b} J. Schaarschmidt,¹⁷¹ P. Schacht,¹⁰¹ B. M. Schachtner,¹⁰⁰ D. Schaefer,³² L. Schaefer,¹²² R. Schaefer,⁴⁴ J. Schaeffer,⁸⁴ S. Schaepe,²³ S. Schaezel,^{59b} U. Schäfer,⁸⁴ A. C. Schaffer,¹¹⁷ D. Schaile,¹⁰⁰ R. D. Schamberger,¹⁴⁸ V. Scharf,^{59a} V. A. Schegelsky,¹²³ D. Scheirich,¹²⁹ M. Schernau,¹⁶² C. Schiavi,^{52a,52b} S. Schier,¹³⁷ C. Schillo,⁵⁰ M. Schioppa,^{39a,39b} S. Schlenker,³² K. R. Schmidt-Sommerfeld,¹⁰¹ K. Schmieden,³² C. Schmitt,⁸⁴ S. Schmitt,⁴⁴ S. Schmitz,⁸⁴ B. Schneider,^{159a} U. Schnoor,⁵⁰ L. Schoeffel,¹³⁶ A. Schoening,^{59b} B. D. Schoenrock,⁹¹ E. Schopf,²³ M. Schott,⁸⁴ J. Schovancova,⁸ S. Schramm,⁵¹ M. Schreyer,¹⁷³ N. Schuh,⁸⁴ A. Schulte,⁸⁴ M. J. Schultens,²³ H.-C. Schultz-Coulon,^{59a} H. Schulz,¹⁷ M. Schumacher,⁵⁰ B. A. Schumm,¹³⁷ Ph. Schune,¹³⁶ A. Schwartzman,¹⁴³ T. A. Schwarz,⁹⁰ H. Schweiger,⁸⁵ Ph. Schwemling,¹³⁶ R. Schwienhorst,⁹¹ J. Schwindling,¹³⁶ T. Schwindt,²³ G. Sciolla,²⁵ F. Scuri,^{124a,124b} F. Scutti,⁸⁹ J. Searcy,⁹⁰ P. Seema,²³ S. C. Seidel,¹⁰⁵ A. Seiden,¹³⁷ F. Seifert,¹²⁸ J. M. Seixas,^{26a} G. Sekhniaidze,^{104a} K. Sekhon,⁹⁰ S. J. Sekula,⁴² D. M. Seliverstov,^{123,a} N. Semprini-Cesari,^{22a,22b} C. Serfon,¹¹⁹ L. Serin,¹¹⁷ L. Serkin,^{163a,163b} M. Sessa,^{134a,134b} R. Seuster,¹⁶⁸ H. Severini,¹¹³ T. Sfiligoj,⁷⁶ F. Sforza,³² A. Sfyrila,⁵¹ E. Shabalina,⁵⁶ N. W. Shaikh,^{146a,146b} L. Y. Shan,^{35a} R. Shang,¹⁶⁵ J. T. Shank,²⁴ M. Shapiro,¹⁶ P. B. Shatalov,⁹⁷ K. Shaw,^{163a,163b} S. M. Shaw,⁸⁵ A. Shcherbakova,^{146a,146b} C. Y. Shehu,¹⁴⁹ P. Sherwood,⁷⁹ L. Shi,^{151,kk} S. Shimizu,⁶⁸ C. O. Shimmin,¹⁶² M. Shimojima,¹⁰² M. Shiyakova,^{66,ll} A. Shmeleva,⁹⁶ D. Shoaleh Saadi,⁹⁵ M. J. Shochet,³³ S. Shojaii,^{92a,92b} S. Shrestha,¹¹¹ E. Shulga,⁹⁸ M. A. Shupe,⁷ P. Sicho,¹²⁷ A. M. Sickles,¹⁶⁵ P. E. Sidebo,¹⁴⁷ O. Sidiropoulou,¹⁷³ D. Sidorov,¹¹⁴ A. Sidoti,^{22a,22b} F. Siegert,⁴⁶ Dj. Sijacki,¹⁴ J. Silva,^{126a,126d} S. B. Silverstein,^{146a} V. Simak,¹²⁸ Lj. Simic,¹⁴ S. Simion,¹¹⁷ E. Simioni,⁸⁴ B. Simmons,⁷⁹ D. Simon,³⁶ M. Simon,⁸⁴ P. Sinervo,¹⁵⁸ N. B. Sinev,¹¹⁶ M. Sioli,^{22a,22b} G. Siragusa,¹⁷³ S. Yu. Sivoklov,⁹⁹ J. Sjölin,^{146a,146b} M. B. Skinner,⁷³ H. P. Skottowe,⁵⁸ P. Skubic,¹¹³ M. Slater,¹⁹ T. Slavicek,¹²⁸ M. Slawinska,¹⁰⁷ K. Sliwa,¹⁶¹ R. Slovak,¹²⁹ V. Smakhtin,¹⁷¹ B. H. Smart,⁵ L. Smestad,¹⁵ J. Smiesko,^{144a} S. Yu. Smirnov,⁹⁸ Y. Smirnov,⁹⁸ L. N. Smirnova,^{99,mm} O. Smirnova,⁸² M. N. K. Smith,³⁷ R. W. Smith,³⁷ M. Smizanska,⁷³ K. Smolek,¹²⁸ A. A. Snesarev,⁹⁶ S. Snyder,²⁷ R. Sobie,^{168,m} F. Socher,⁴⁶ A. Soffer,¹⁵³ D. A. Soh,¹⁵¹ G. Sokhrannyi,⁷⁶ C. A. Solans Sanchez,³² M. Solar,¹²⁸ E. Yu. Soldatov,⁹⁸ U. Soldevila,¹⁶⁶ A. A. Solodkov,¹³⁰ A. Soloshenko,⁶⁶ O. V. Solovyanov,¹³⁰ V. Solovyev,¹²³ P. Sommer,⁵⁰ H. Son,¹⁶¹ H. Y. Song,^{35b,nn} A. Sood,¹⁶ A. Sopczak,¹²⁸ V. Sopko,¹²⁸ V. Sorin,¹³ D. Sosa,^{59b} C. L. Sotiropoulou,^{124a,124b} R. Soualah,^{163a,163c} A. M. Soukharev,^{109,d} D. South,⁴⁴ B. C. Sowden,⁷⁸ S. Spagnolo,^{74a,74b} M. Spalla,^{124a,124b}

M. Spangenberg,¹⁶⁹ F. Spanò,⁷⁸ D. Sperlich,¹⁷ F. Spettel,¹⁰¹ R. Spighi,^{22a} G. Spigo,³² L. A. Spiller,⁸⁹ M. Spousta,¹²⁹ R. D. St. Denis,^{55,a} A. Stabile,^{92a} R. Stamen,^{59a} S. Stamm,¹⁷ E. Stanecka,⁴¹ R. W. Staneck,⁶ C. Stancu,^{134a} M. Stancu-Bellu,⁴⁴ M. M. Stanitzki,⁴⁴ S. Stapnes,¹¹⁹ E. A. Starchenko,¹³⁰ G. H. Stark,³³ J. Stark,⁵⁷ P. Staroba,¹²⁷ P. Starovoitov,^{59a} S. Stärz,³² R. Staszewski,⁴¹ P. Steinberg,²⁷ B. Stelzer,¹⁴² H. J. Stelzer,³² O. Stelzer-Chilton,^{159a} H. Stenzel,⁵⁴ G. A. Stewart,⁵⁵ J. A. Stillings,²³ M. C. Stockton,⁸⁸ M. Stoebe,⁸⁸ G. Stoicea,^{28b} P. Stolte,⁵⁶ S. Stonjek,¹⁰¹ A. R. Stradling,⁸ A. Straessner,⁴⁶ M. E. Stramaglia,¹⁸ J. Strandberg,¹⁴⁷ S. Strandberg,^{146a,146b} A. Strandlie,¹¹⁹ M. Strauss,¹¹³ P. Strizenec,^{144b} R. Ströhmer,¹⁷³ D. M. Strom,¹¹⁶ R. Stroynowski,⁴² A. Strubig,¹⁰⁶ S. A. Stucci,²⁷ B. Stugu,¹⁵ N. A. Styles,⁴⁴ D. Su,¹⁴³ J. Su,¹²⁵ S. Suchek,^{59a} Y. Sugaya,¹¹⁸ M. Suk,¹²⁸ V. V. Sulin,⁹⁶ S. Sultansoy,^{4c} T. Sumida,⁶⁹ S. Sun,⁵⁸ X. Sun,^{35a} J. E. Sundermann,⁵⁰ K. Suruliz,¹⁴⁹ G. Susinno,^{39a,39b} M. R. Sutton,¹⁴⁹ S. Suzuki,⁶⁷ M. Svatos,¹²⁷ M. Swiatlowski,³³ I. Sykora,^{144a} T. Sykora,¹²⁹ D. Ta,⁵⁰ C. Taccini,^{134a,134b} K. Tackmann,⁴⁴ J. Taenzer,¹⁵⁸ A. Taffard,¹⁶² R. Tafiout,^{159a} N. Taiblum,¹⁵³ H. Takai,²⁷ R. Takashima,⁷⁰ T. Takeshita,¹⁴⁰ Y. Takubo,⁶⁷ M. Talby,⁸⁶ A. A. Talyshev,^{109,d} K. G. Tan,⁸⁹ J. Tanaka,¹⁵⁵ M. Tanaka,¹⁵⁷ R. Tanaka,¹¹⁷ S. Tanaka,⁶⁷ B. B. Tannenwald,¹¹¹ S. Tapia Araya,^{34b} S. Tapprogge,⁸⁴ S. Tarem,¹⁵² G. F. Tartarelli,^{92a} P. Tas,¹²⁹ M. Tasevsky,¹²⁷ T. Tashiro,⁶⁹ E. Tassi,^{39a,39b} A. Tavares Delgado,^{126a,126b} Y. Tayalati,^{135e} A. C. Taylor,¹⁰⁵ G. N. Taylor,⁸⁹ P. T. E. Taylor,⁸⁹ W. Taylor,^{159b} F. A. Teischinger,³² P. Teixeira-Dias,⁷⁸ K. K. Temming,⁵⁰ D. Temple,¹⁴² H. Ten Kate,³² P. K. Teng,¹⁵¹ J. J. Teoh,¹¹⁸ F. Tepel,¹⁷⁴ S. Terada,⁶⁷ K. Terashi,¹⁵⁵ J. Terron,⁸³ S. Terzo,¹⁰¹ M. Testa,⁴⁹ R. J. Teuscher,^{158,m} T. Theveneaux-Pelzer,⁸⁶ J. P. Thomas,¹⁹ J. Thomas-Wilsker,⁷⁸ E. N. Thompson,³⁷ P. D. Thompson,¹⁹ A. S. Thompson,⁵⁵ L. A. Thomsen,¹⁷⁵ E. Thomson,¹²² M. Thomson,³⁰ M. J. Tibbetts,¹⁶ R. E. Tice Torres,⁸⁶ V. O. Tikhomirov,^{96,oo} Yu. A. Tikhonov,^{109,d} S. Timoshenko,⁹⁸ P. Tipton,¹⁷⁵ S. Tisserant,⁸⁶ K. Todome,¹⁵⁷ T. Todorov,^{5,a} S. Todorova-Nova,¹²⁹ J. Tojo,⁷¹ S. Tokár,^{144a} K. Tokushuku,⁶⁷ E. Tolley,⁵⁸ L. Tomlinson,⁸⁵ M. Tomoto,¹⁰³ L. Tompkins,^{143,pp} K. Toms,¹⁰⁵ B. Tong,⁵⁸ E. Torrence,¹¹⁶ H. Torres,¹⁴² E. Torró Pastor,¹³⁸ J. Toth,^{86,qq} F. Touchard,⁸⁶ D. R. Tovey,¹³⁹ T. Trefzger,¹⁷³ A. Tricoli,²⁷ I. M. Trigger,^{159a} S. Trincaz-Duvoid,⁸¹ M. F. Tripiana,¹³ W. Trischuk,¹⁵⁸ B. Trocmé,⁵⁷ A. Trofymov,⁴⁴ C. Troncon,^{92a} M. Trotter-McDonald,¹⁶ M. Trovatelli,¹⁶⁸ L. Truong,^{163a,163c} M. Trzebinski,⁴¹ A. Trzupek,⁴¹ J. C-L. Tseng,¹²⁰ P. V. Tsiarshka,⁹³ G. Tsipolitis,¹⁰ N. Tsirintanis,⁹ S. Tsiskaridze,¹³ V. Tsiskaridze,⁵⁰ E. G. Tskhadadze,^{53a} K. M. Tsui,^{61a} I. I. Tsukerman,⁹⁷ V. Tsulaia,¹⁶ S. Tsuno,⁶⁷ D. Tsybychev,¹⁴⁸ Y. Tu,^{61b} A. Tudorache,^{28b} V. Tudorache,^{28b} A. N. Tuna,⁵⁸ S. A. Tupputi,^{22a,22b} S. Turchikhin,⁶⁶ D. Turecek,¹²⁸ D. Turgeman,¹⁷¹ R. Turra,^{92a,92b} A. J. Turvey,⁴² P. M. Tuts,³⁷ M. Tyndel,¹³¹ G. Uccielli,^{22a,22b} I. Ueda,¹⁵⁵ M. Ughetto,^{146a,146b} F. Ukegawa,¹⁶⁰ G. Unal,³² A. Undrus,²⁷ G. Unel,¹⁶² F. C. Ungaro,⁸⁹ Y. Unno,⁶⁷ C. Unverdorben,¹⁰⁰ J. Urban,^{144b} P. Urquijo,⁸⁹ P. Urrejola,⁸⁴ G. Usai,⁸ A. Usanova,⁶³ L. Vacavant,⁸⁶ V. Vacek,¹²⁸ B. Vachon,⁸⁸ C. Valderanis,¹⁰⁰ E. Valdes Santurio,^{146a,146b} N. Valencic,¹⁰⁷ S. Valentinetti,^{22a,22b} A. Valero,¹⁶⁶ L. Valery,¹³ S. Valkar,¹²⁹ J. A. Valls Ferrer,¹⁶⁶ W. Van Den Wollenberg,¹⁰⁷ P. C. Van Der Deijl,¹⁰⁷ H. van der Graaf,¹⁰⁷ N. van Eldik,¹⁵² P. van Gemmeren,⁶ J. Van Nieuwkoop,¹⁴² I. van Vulpen,¹⁰⁷ M. C. van Woerden,³² M. Vanadia,^{132a,132b} W. Vandelli,³² R. Vanguri,¹²² A. Vaniachine,¹³⁰ P. Vankov,¹⁰⁷ G. Vardanyan,¹⁷⁶ R. Vari,^{132a} E. W. Varnes,⁷ T. Varol,⁴² D. Varouchas,⁸¹ A. Vartapetian,⁸ K. E. Varvell,¹⁵⁰ J. G. Vasquez,¹⁷⁵ F. Vazeille,³⁶ T. Vazquez Schroeder,⁸⁸ J. Veatch,⁵⁶ V. Veeraraghavan,⁷ L. M. Veloce,¹⁵⁸ F. Veloso,^{126a,126c} S. Veneziano,^{132a} A. Ventura,^{74a,74b} M. Venturi,¹⁶⁸ N. Venturi,¹⁵⁸ A. Venturini,²⁵ V. Vercesi,^{121a} M. Verducci,^{132a,132b} W. Verkerke,¹⁰⁷ J. C. Vermeulen,¹⁰⁷ A. Vest,^{46,rr} M. C. Vetterli,^{142,e} O. Viazlo,⁸² I. Vichou,^{165,a} T. Vickey,¹³⁹ O. E. Vickey Boeriu,¹³⁹ G. H. A. Viehhauser,¹²⁰ S. Viel,¹⁶ L. Vignani,¹²⁰ M. Villa,^{22a,22b} M. Villaplana Perez,^{92a,92b} E. Vilucchi,⁴⁹ M. G. Vincet,³¹ V. B. Vinogradov,⁶⁶ C. Vittori,^{22a,22b} I. Vivarelli,¹⁴⁹ S. Vlachos,¹⁰ M. Vlasak,¹²⁸ M. Vogel,¹⁷⁴ P. Vokac,¹²⁸ G. Volpi,^{124a,124b} M. Volpi,⁸⁹ H. von der Schmitt,¹⁰¹ E. von Toerne,²³ V. Vorobel,¹²⁹ K. Vorobev,⁹⁸ M. Vos,¹⁶⁶ R. Voss,³² J. H. Vossebeld,⁷⁵ N. Vranjes,¹⁴ M. Vranjes Milosavljevic,¹⁴ V. Vrba,¹²⁷ M. Vreeswijk,¹⁰⁷ R. Vuillermet,³² I. Vukotic,³³ Z. Vykydal,¹²⁸ P. Wagner,²³ W. Wagner,¹⁷⁴ H. Wahlberg,⁷² S. Wahrmund,⁴⁶ J. Wakabayashi,¹⁰³ J. Walder,⁷³ R. Walker,¹⁰⁰ W. Walkowiak,¹⁴¹ V. Wallangen,^{146a,146b} C. Wang,^{35c} C. Wang,^{35d,86} F. Wang,¹⁷² H. Wang,¹⁶ H. Wang,⁴² J. Wang,⁴⁴ J. Wang,¹⁵⁰ K. Wang,⁸⁸ R. Wang,⁶ S. M. Wang,¹⁵¹ T. Wang,²³ T. Wang,³⁷ W. Wang,^{35b} X. Wang,¹⁷⁵ C. Wanotayaroj,¹¹⁶ A. Warburton,⁸⁸ C. P. Ward,³⁰ D. R. Wardrope,⁷⁹ A. Washbrook,⁴⁸ P. M. Watkins,¹⁹ A. T. Watson,¹⁹ M. F. Watson,¹⁹ G. Watts,¹³⁸ S. Watts,⁸⁵ B. M. Waugh,⁷⁹ S. Webb,⁸⁴ M. S. Weber,¹⁸ S. W. Weber,¹⁷³ J. S. Webster,⁶ A. R. Weidberg,¹²⁰ B. Weinert,⁶² J. Weingarten,⁵⁶ C. Weiser,⁵⁰ H. Weits,¹⁰⁷ P. S. Wells,³² T. Wenaus,²⁷ T. Wengler,³² S. Wenig,³² N. Wermes,²³ M. Werner,⁵⁰ M. D. Werner,⁶⁵ P. Werner,³² M. Wessels,^{59a} J. Wetter,¹⁶¹ K. Whalen,¹¹⁶ N. L. Whallon,¹³⁸ A. M. Wharton,⁷³ A. White,⁸ M. J. White,¹ R. White,^{34b} D. Whiteson,¹⁶² F. J. Wickens,¹³¹ W. Wiedenmann,¹⁷² M. Wielders,¹³¹ P. Wienemann,²³ C. Wiglesworth,³⁸ L. A. M. Wiik-Fuchs,²³ A. Wildauer,¹⁰¹ F. Wilk,⁸⁵ H. G. Wilkens,³² H. H. Williams,¹²² S. Williams,¹⁰⁷ C. Willis,⁹¹ S. Willocq,⁸⁷ J. A. Wilson,¹⁹ I. Wingerter-Seez,⁵ F. Winklmeier,¹¹⁶ O. J. Winston,¹⁴⁹ B. T. Winter,²³ M. Wittgen,¹⁴³

J. Wittkowski,¹⁰⁰ T. M. H. Wolf,¹⁰⁷ M. W. Wolter,⁴¹ H. Wolters,^{126a,126c} S. D. Worm,¹³¹ B. K. Wosiek,⁴¹ J. Wotschack,³² M. J. Woudstra,⁸⁵ K. W. Wozniak,⁴¹ M. Wu,⁵⁷ M. Wu,³³ S. L. Wu,¹⁷² X. Wu,⁵¹ Y. Wu,⁹⁰ T. R. Wyatt,⁸⁵ B. M. Wynne,⁴⁸ S. Xella,³⁸ D. Xu,^{35a} L. Xu,²⁷ B. Yabsley,¹⁵⁰ S. Yacoob,^{145a} D. Yamaguchi,¹⁵⁷ Y. Yamaguchi,¹¹⁸ A. Yamamoto,⁶⁷ S. Yamamoto,¹⁵⁵ T. Yamanaka,¹⁵⁵ K. Yamauchi,¹⁰³ Y. Yamazaki,⁶⁸ Z. Yan,²⁴ H. Yang,^{35e} H. Yang,¹⁷² Y. Yang,¹⁵¹ Z. Yang,¹⁵ W.-M. Yao,¹⁶ Y. C. Yap,⁸¹ Y. Yasu,⁶⁷ E. Yatsenko,⁵ K. H. Yau Wong,²³ J. Ye,⁴² S. Ye,²⁷ I. Yeletsikh,⁶⁶ A. L. Yen,⁵⁸ E. Yildirim,⁸⁴ K. Yoritani,¹⁷⁰ R. Yoshida,⁶ K. Yoshihara,¹²² C. Young,¹⁴³ C. J. S. Young,³² S. Youssef,²⁴ D. R. Yu,¹⁶ J. Yu,⁸ J. M. Yu,⁹⁰ J. Yu,⁶⁵ L. Yuan,⁶⁸ S. P. Y. Yuen,²³ I. Yusuf,^{30,ss} B. Zabinski,⁴¹ R. Zaidan,^{35d} A. M. Zaitsev,^{130,ff} N. Zakharchuk,⁴⁴ J. Zalieckas,¹⁵ A. Zaman,¹⁴⁸ S. Zambito,⁵⁸ L. Zanello,^{132a,132b} D. Zanzi,⁸⁹ C. Zeitnitz,¹⁷⁴ M. Zeman,¹²⁸ A. Zemla,^{40a} J. C. Zeng,¹⁶⁵ Q. Zeng,¹⁴³ K. Zengel,²⁵ O. Zenin,¹³⁰ T. Ženiš,^{144a} D. Zerwas,¹¹⁷ D. Zhang,⁹⁰ F. Zhang,¹⁷² G. Zhang,^{35b,nn} H. Zhang,^{35c} J. Zhang,⁶ L. Zhang,⁵⁰ R. Zhang,²³ R. Zhang,^{35b,tt} X. Zhang,^{35d} Z. Zhang,¹¹⁷ X. Zhao,⁴² Y. Zhao,^{35d} Z. Zhao,^{35b} A. Zhemchugov,⁶⁶ J. Zhong,¹²⁰ B. Zhou,⁹⁰ C. Zhou,⁴⁷ L. Zhou,³⁷ L. Zhou,⁴² M. Zhou,¹⁴⁸ N. Zhou,^{35f} C. G. Zhu,^{35d} H. Zhu,^{35a} J. Zhu,⁹⁰ Y. Zhu,^{35b} X. Zhuang,^{35a} K. Zhukov,⁹⁶ A. Zibell,¹⁷³ D. Zieminska,⁶² N. I. Zimine,⁶⁶ C. Zimmermann,⁸⁴ S. Zimmermann,⁵⁰ Z. Zinonos,⁵⁶ M. Zinser,⁸⁴ M. Ziolkowski,¹⁴¹ L. Živković,¹⁴ G. Zobernig,¹⁷² A. Zoccoli,^{22a,22b} M. zur Nedden,¹⁷ and L. Zwalinski³²

(ATLAS Collaboration)

¹*Department of Physics, University of Adelaide, Adelaide, Australia*²*Physics Department, SUNY Albany, Albany, New York, USA*³*Department of Physics, University of Alberta, Edmonton, Alberta, Canada*^{4a}*Department of Physics, Ankara University, Ankara, Turkey*^{4b}*Istanbul Aydin University, Istanbul, Turkey*^{4c}*Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey*⁵*LAPP, CNRS/IN2P3 and Université Savoie Mont Blanc, Annecy-le-Vieux, France*⁶*High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois, USA*⁷*Department of Physics, University of Arizona, Tucson, Arizona, USA*⁸*Department of Physics, The University of Texas at Arlington, Arlington, Texas, USA*⁹*Physics Department, University of Athens, Athens, Greece*¹⁰*Physics Department, National Technical University of Athens, Zografou, Greece*¹¹*Department of Physics, The University of Texas at Austin, Austin, Texas, USA*¹²*Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*¹³*Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Barcelona, Spain*¹⁴*Institute of Physics, University of Belgrade, Belgrade, Serbia*¹⁵*Department for Physics and Technology, University of Bergen, Bergen, Norway*¹⁶*Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, California, USA*¹⁷*Department of Physics, Humboldt University, Berlin, Germany*¹⁸*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*¹⁹*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*^{20a}*Department of Physics, Bogazici University, Istanbul, Turkey*^{20b}*Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey*^{20c}*Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*^{20d}*Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*²¹*Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia*^{22a}*INFN Sezione di Bologna, Italy*^{22b}*Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy*²³*Physikalisches Institut, University of Bonn, Bonn, Germany*²⁴*Department of Physics, Boston University, Boston, Massachusetts, USA*²⁵*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*^{26a}*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil*^{26b}*Electrical Circuits Department, Federal University of Juiz de Fora (UFJF), Juiz de Fora, Brazil*^{26c}*Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei, Brazil*^{26d}*Instituto de Física, Universidade de Sao Paulo, Sao Paulo, Brazil*²⁷*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*^{28a}*Transilvania University of Brasov, Brasov, Romania, Romania*^{28b}*National Institute of Physics and Nuclear Engineering, Bucharest, Romania*

- ^{28c}*National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj Napoca, Romania*
- ^{28d}*University Politehnica Bucharest, Bucharest, Romania*
- ^{28e}*West University in Timisoara, Timisoara, Romania*
- ²⁹*Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina*
- ³⁰*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
- ³¹*Department of Physics, Carleton University, Ottawa, Ontario, Canada*
- ³²*CERN, Geneva, Switzerland*
- ³³*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
- ^{34a}*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*
- ^{34b}*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
- ^{35a}*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
- ^{35b}*Department of Modern Physics, University of Science and Technology of China, Anhui, China*
- ^{35c}*Department of Physics, Nanjing University, Jiangsu, China*
- ^{35d}*School of Physics, Shandong University, Shandong, China*
- ^{35e}*Department of Physics and Astronomy, Shanghai Key Laboratory for Particle Physics and Cosmology, Shanghai Jiao Tong University, Shanghai; (also affiliated with PKU-CHEP), China*
- ^{35f}*Physics Department, Tsinghua University, Beijing 100084, China*
- ³⁶*Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France*
- ³⁷*Nevis Laboratory, Columbia University, Irvington, New York, USA*
- ³⁸*Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
- ^{39a}*INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy*
- ^{39b}*Dipartimento di Fisica, Università della Calabria, Rende, Italy*
- ^{40a}*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*
- ^{40b}*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
- ⁴¹*Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
- ⁴²*Physics Department, Southern Methodist University, Dallas, Texas, USA*
- ⁴³*Physics Department, University of Texas at Dallas, Richardson, Texas, USA*
- ⁴⁴*DESY, Hamburg and Zeuthen, Germany*
- ⁴⁵*Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany*
- ⁴⁶*Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
- ⁴⁷*Department of Physics, Duke University, Durham, North Carolina, USA*
- ⁴⁸*SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
- ⁴⁹*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
- ⁵⁰*Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany*
- ⁵¹*Section de Physique, Université de Genève, Geneva, Switzerland*
- ^{52a}*INFN Sezione di Genova, Italy*
- ^{52b}*Dipartimento di Fisica, Università di Genova, Genova, Italy*
- ^{53a}*E. Andronikashvili Institute of Physics, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*
- ^{53b}*High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
- ⁵⁴*II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
- ⁵⁵*SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
- ⁵⁶*II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany*
- ⁵⁷*Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France*
- ⁵⁸*Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA*
- ^{59a}*Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- ^{59b}*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- ^{59c}*ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany*
- ⁶⁰*Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan*
- ^{61a}*Department of Physics, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China*
- ^{61b}*Department of Physics, The University of Hong Kong, Hong Kong, China*
- ^{61c}*Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
- ⁶²*Department of Physics, Indiana University, Bloomington, Indiana, USA*
- ⁶³*Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*
- ⁶⁴*University of Iowa, Iowa City, Iowa, USA*
- ⁶⁵*Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA*
- ⁶⁶*Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia*
- ⁶⁷*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
- ⁶⁸*Graduate School of Science, Kobe University, Kobe, Japan*

- ⁶⁹Faculty of Science, Kyoto University, Kyoto, Japan
⁷⁰Kyoto University of Education, Kyoto, Japan
⁷¹Department of Physics, Kyushu University, Fukuoka, Japan
⁷²Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
⁷³Physics Department, Lancaster University, Lancaster, United Kingdom
^{74a}INFN Sezione di Lecce, Italy
^{74b}Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
⁷⁵Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
⁷⁶Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
⁷⁷School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
⁷⁸Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
⁷⁹Department of Physics and Astronomy, University College London, London, United Kingdom
⁸⁰Louisiana Tech University, Ruston, Louisiana, USA
⁸¹Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
⁸²Fysiska institutionen, Lunds universitet, Lund, Sweden
⁸³Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain
⁸⁴Institut für Physik, Universität Mainz, Mainz, Germany
⁸⁵School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
⁸⁶CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
⁸⁷Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA
⁸⁸Department of Physics, McGill University, Montreal, Québec, Canada
⁸⁹School of Physics, University of Melbourne, Victoria, Australia
⁹⁰Department of Physics, The University of Michigan, Ann Arbor, Michigan, USA
⁹¹Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA
^{92a}INFN Sezione di Milano, Italy
^{92b}Dipartimento di Fisica, Università di Milano, Milano, Italy
⁹³B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
⁹⁴National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
⁹⁵Group of Particle Physics, University of Montreal, Montreal, Québec, Canada
⁹⁶P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
⁹⁷Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
⁹⁸National Research Nuclear University MEPhI, Moscow, Russia
⁹⁹D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia
¹⁰⁰Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
¹⁰¹Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
¹⁰²Nagasaki Institute of Applied Science, Nagasaki, Japan
¹⁰³Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
^{104a}INFN Sezione di Napoli, Italy
^{104b}Dipartimento di Fisica, Università di Napoli, Napoli, Italy
¹⁰⁵Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA
¹⁰⁶Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
¹⁰⁷Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
¹⁰⁸Department of Physics, Northern Illinois University, DeKalb, Illinois, USA
¹⁰⁹Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
¹¹⁰Department of Physics, New York University, New York, New York, USA
¹¹¹Ohio State University, Columbus, Ohio, USA
¹¹²Faculty of Science, Okayama University, Okayama, Japan
¹¹³Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA
¹¹⁴Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA
¹¹⁵Palacký University, RCPTM, Olomouc, Czech Republic
¹¹⁶Center for High Energy Physics, University of Oregon, Eugene, Oregon, USA
¹¹⁷LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France
¹¹⁸Graduate School of Science, Osaka University, Osaka, Japan
¹¹⁹Department of Physics, University of Oslo, Oslo, Norway
¹²⁰Department of Physics, Oxford University, Oxford, United Kingdom
^{121a}INFN Sezione di Pavia, Italy
^{121b}Dipartimento di Fisica, Università di Pavia, Pavia, Italy
¹²²Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA
¹²³National Research Centre “Kurchatov Institute” B.P. Konstantinov Petersburg Nuclear Physics Institute, St. Petersburg, Russia
^{124a}INFN Sezione di Pisa, Italy

- ^{124b}*Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*
- ¹²⁵*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA*
- ^{126a}*Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa, Portugal*
- ^{126b}*Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal*
- ^{126c}*Department of Physics, University of Coimbra, Coimbra, Portugal*
- ^{126d}*Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal*
- ^{126e}*Departamento de Física, Universidade do Minho, Braga, Portugal*
- ^{126f}*Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada (Spain), Portugal*
- ^{126g}*Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal*
- ¹²⁷*Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic*
- ¹²⁸*Czech Technical University in Prague, Praha, Czech Republic*
- ¹²⁹*Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic*
- ¹³⁰*State Research Center Institute for High Energy Physics, NRC KI, Protvino, Russia*
- ¹³¹*Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
- ^{132a}*INFN Sezione di Roma, Italy*
- ^{132b}*Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*
- ^{133a}*INFN Sezione di Roma Tor Vergata, Italy*
- ^{133b}*Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*
- ^{134a}*INFN Sezione di Roma Tre, Italy*
- ^{134b}*Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*
- ^{135a}*Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca, Morocco*
- ^{135b}*Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat, Morocco*
- ^{135c}*Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco*
- ^{135d}*Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco*
- ^{135e}*Faculté des sciences, Université Mohammed V, Rabat, Morocco*
- ¹³⁶*DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France*
- ¹³⁷*Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA*
- ¹³⁸*Department of Physics, University of Washington, Seattle, Washington, USA*
- ¹³⁹*Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
- ¹⁴⁰*Department of Physics, Shinshu University, Nagano, Japan*
- ¹⁴¹*Fachbereich Physik, Universität Siegen, Siegen, Germany*
- ¹⁴²*Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada*
- ¹⁴³*SLAC National Accelerator Laboratory, Stanford, California, USA*
- ^{144a}*Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava, Slovak Republic*
- ^{144b}*Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
- ^{145a}*Department of Physics, University of Cape Town, Cape Town, South Africa*
- ^{145b}*Department of Physics, University of Johannesburg, Johannesburg, South Africa*
- ^{145c}*School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
- ^{146a}*Department of Physics, Stockholm University, Sweden*
- ^{146b}*The Oskar Klein Centre, Stockholm, Sweden*
- ¹⁴⁷*Physics Department, Royal Institute of Technology, Stockholm, Sweden*
- ¹⁴⁸*Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook, New York, USA*
- ¹⁴⁹*Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
- ¹⁵⁰*School of Physics, University of Sydney, Sydney, Australia*
- ¹⁵¹*Institute of Physics, Academia Sinica, Taipei, Taiwan*
- ¹⁵²*Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel*
- ¹⁵³*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
- ¹⁵⁴*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
- ¹⁵⁵*International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan*
- ¹⁵⁶*Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*
- ¹⁵⁷*Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
- ¹⁵⁸*Department of Physics, University of Toronto, Toronto, Ontario, Canada*
- ^{159a}*TRIUMF, Vancouver, British Columbia, Canada*
- ^{159b}*Department of Physics and Astronomy, York University, Toronto, Ontario, Canada*
- ¹⁶⁰*Faculty of Pure and Applied Sciences, and Center for Integrated Research in Fundamental Science and Engineering, University of Tsukuba, Tsukuba, Japan*
- ¹⁶¹*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*
- ¹⁶²*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*

- ^{163a}*INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy*
^{163b}*ICTP, Trieste, Italy*
^{163c}*Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy*
¹⁶⁴*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
¹⁶⁵*Department of Physics, University of Illinois, Urbana, Illinois, USA*
¹⁶⁶*Instituto de Física Corpuscular (IFIC) and Departamento de Física Atomica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain*
¹⁶⁷*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*
¹⁶⁸*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*
¹⁶⁹*Department of Physics, University of Warwick, Coventry, United Kingdom*
¹⁷⁰*Waseda University, Tokyo, Japan*
¹⁷¹*Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel*
¹⁷²*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*
¹⁷³*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany*
¹⁷⁴*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
¹⁷⁵*Department of Physics, Yale University, New Haven, Connecticut, USA*
¹⁷⁶*Yerevan Physics Institute, Yerevan, Armenia*
¹⁷⁷*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*

^aDeceased.

^bAlso at Department of Physics, King's College London, London, United Kingdom.

^cAlso at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

^dAlso at Novosibirsk State University, Novosibirsk, Russia.

^eAlso at TRIUMF, Vancouver BC, Canada.

^fAlso at Department of Physics & Astronomy, University of Louisville, Louisville, KY, USA.

^gAlso at Department of Physics, California State University, Fresno CA, USA.

^hAlso at Department of Physics, University of Fribourg, Fribourg, Switzerland.

ⁱAlso at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain.

^jAlso at Departamento de Física e Astronomia, Faculdade de Ciências, Universidade do Porto, Portugal.

^kAlso at Tomsk State University, Tomsk, Russia.

^lAlso at Università di Napoli Parthenope, Napoli, Italy.

^mAlso at Institute of Particle Physics (IPP), Canada.

ⁿAlso at National Institute of Physics and Nuclear Engineering, Bucharest, Romania.

^oAlso at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.

^pAlso at Department of Physics, The University of Michigan, Ann Arbor MI, USA.

^qAlso at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa.

^rAlso at Louisiana Tech University, Ruston LA, USA.

^sAlso at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.

^tAlso at Graduate School of Science, Osaka University, Osaka, Japan.

^uAlso at Department of Physics, National Tsing Hua University, Taiwan.

^vAlso at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands.

^wAlso at Department of Physics, The University of Texas at Austin, Austin TX, USA.

^xAlso at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.

^yAlso at CERN, Geneva, Switzerland.

^zAlso at Georgian Technical University (GTU), Tbilisi, Georgia.

^{aa}Also at O Chadai Academic Production, Ochanomizu University, Tokyo, Japan.

^{bb}Also at Manhattan College, New York NY, USA.

^{cc}Also at Hellenic Open University, Patras, Greece.

^{dd}Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.

^{ee}Also at School of Physics, Shandong University, Shandong, China.

^{ff}Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.

^{gg}Also at Section de Physique, Université de Genève, Geneva, Switzerland.

^{hh}Also at Eotvos Lorand University, Budapest, Hungary.

ⁱⁱAlso at International School for Advanced Studies (SISSA), Trieste, Italy.

^{jj}Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, USA.

^{kk}Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China.

^{ll}Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.

^{mm}Also at Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia.

ⁿⁿAlso at Institute of Physics, Academia Sinica, Taipei, Taiwan.

^{oo}Also at National Research Nuclear University MEPhI, Moscow, Russia.

^{pp}Also at Department of Physics, Stanford University, Stanford CA, USA.

^{qq}Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.

^{rr}Also at Flensburg University of Applied Sciences, Flensburg, Germany.

^{ss}Also at University of Malaya, Department of Physics, Kuala Lumpur, Malaysia.

^{tt}Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.